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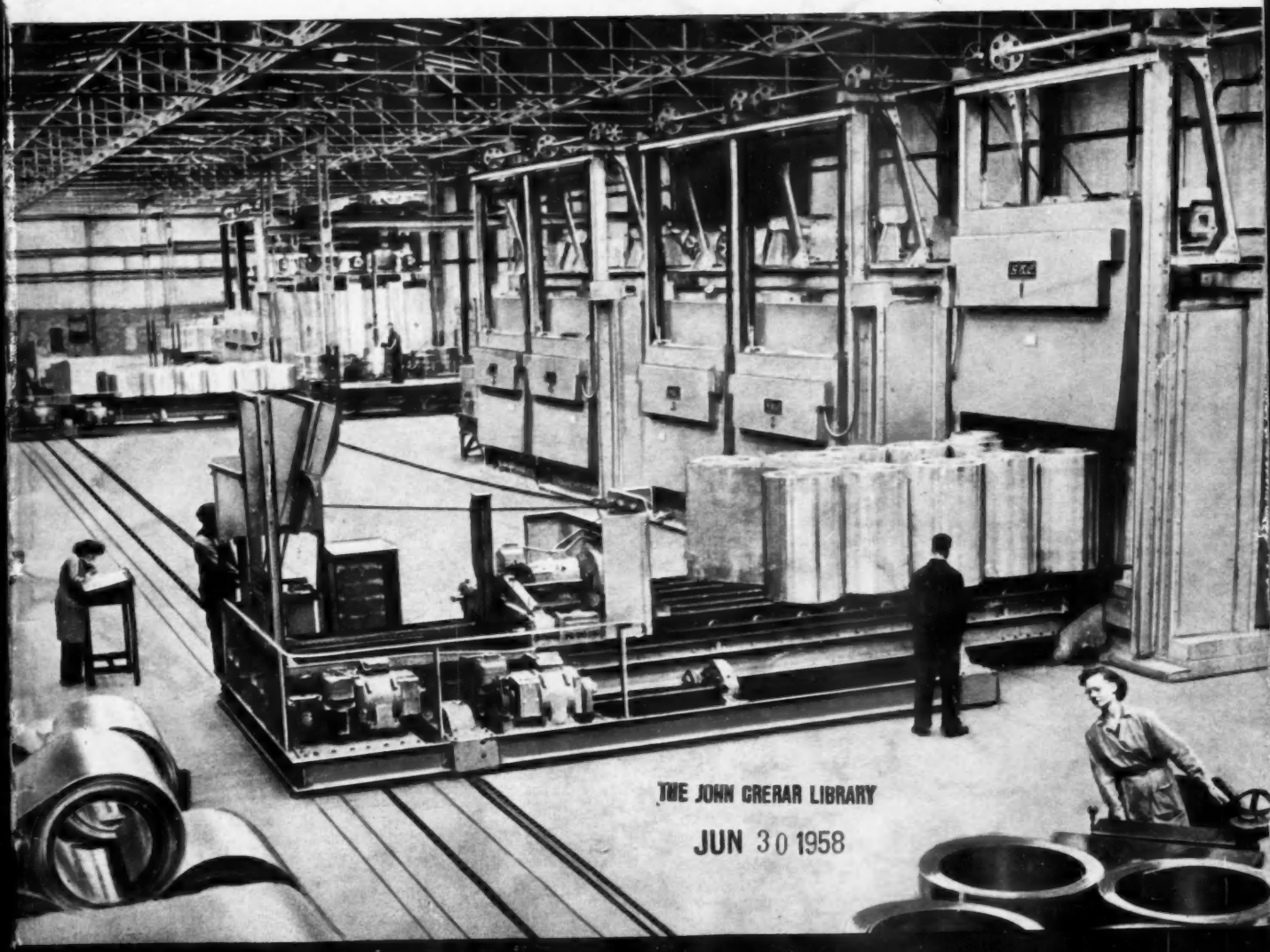

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THE GENERAL ELECTRIC COMPANY LIMITED OF ENGLAND

Volume 25, number 2

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COVER PICTURE

A 300 kW mechanical hearth furnace and three 720 kW twin-hearth batch furnaces in the Annealing Department at the Falkirk Works of the British Aluminium Co. Ltd.

G.E.C. JOURNAL

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[Official Admiralty photograph

H.M.S. " Victorious ", the most advanced aircraft carrier in the world today.
All the aircraft lifts, ammunition and bomb hoists, and hangar door-operating gear, were made at the Erith Engineering Works.

Building the Hunterston Nuclear Power Station

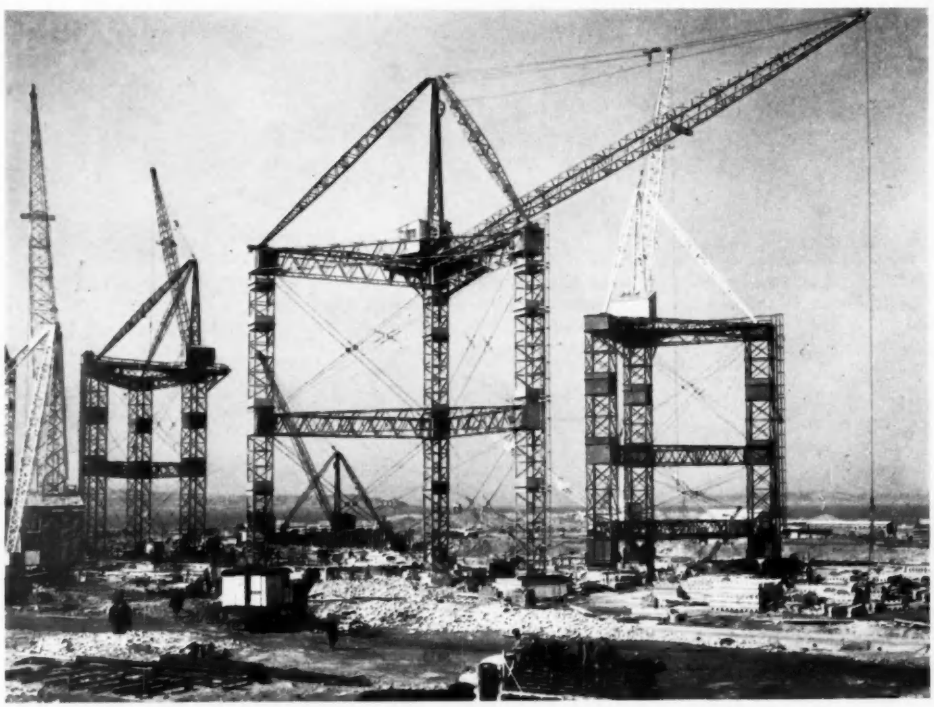

Fig. 1.—Site of Reactor "A" showing the derricks which are being used for placing the main structural concrete.

TEMPORARY works were started in August last year at the site of the Hunterston nuclear power station,* but permission to begin permanent work on this 360 MW station for the South of Scotland Electricity Board was not granted until the middle of October. By that time, 1½ miles of temporary road had been laid to permit the access of heavy civil engineering equipment, and much work had been done to confirm and extend existing information about the rock formation. With the work now in full swing, more than 1,000 men are employed on this 70 acre site on the Ayrshire coast of Scotland. The station is being built by the G.E.C. in association with Simon-Carves Ltd., the Motherwell Bridge & Engineering Co. Ltd., and Mowlem (Scotland) Ltd.

During the first year on site, the emphasis on temporary works is necessarily greater than in subsequent years, but the early stages of the main constructional programme are proceeding according to schedule. Attention has been concentrated largely on the foundations of the first reactor and the turbine hall.

Having removed, on average, eight feet of surface soil and green rock at the reactor base, blasting and excavation began on the foundations to cut out any faults and to produce a level surface prior to mass concreting. This mass concreting involved the pouring of 3,000 cu. yd. of concrete, and a reinforced concrete raft is now being built above it. The raft will incorporate 8,000 cu. yd. of concrete with 400 tons of reinforcing steel. In addition to the cranes used for transferring the concrete from the batching plant to the reactor base, four derricks required for erecting the main concrete structure are now in use (fig. 1).

The turbine-hall excavation covers an area approximately 675 ft. x 130 ft. and goes to a depth of about 13 ft. ; it is now almost finished and work has begun on

* *G.E.C. Journal*, Vol. 24, pp. 3-5, January, 1957.

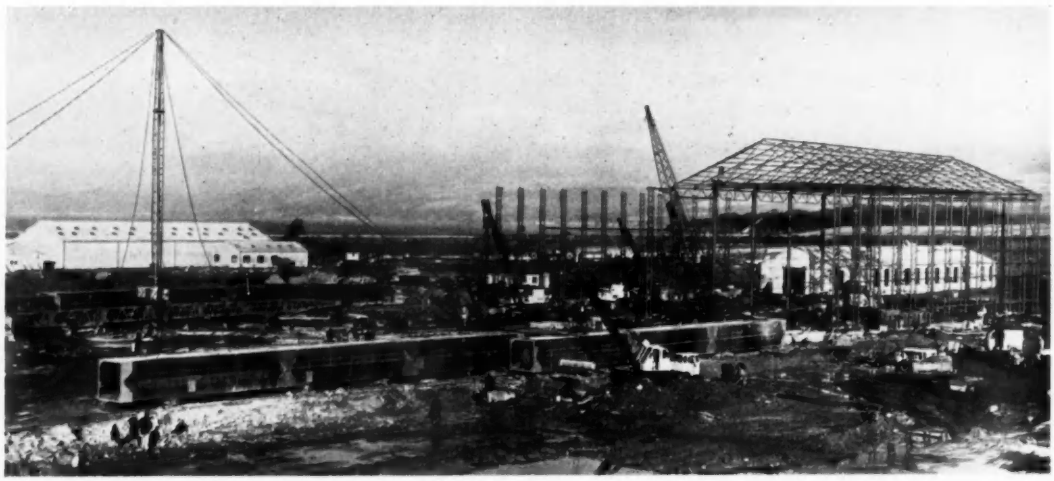

Fig. 2.—Sections of the legs for the 350 ton Goliath crane are seen in front of the workshop being built for assembly of the steam-raising units.

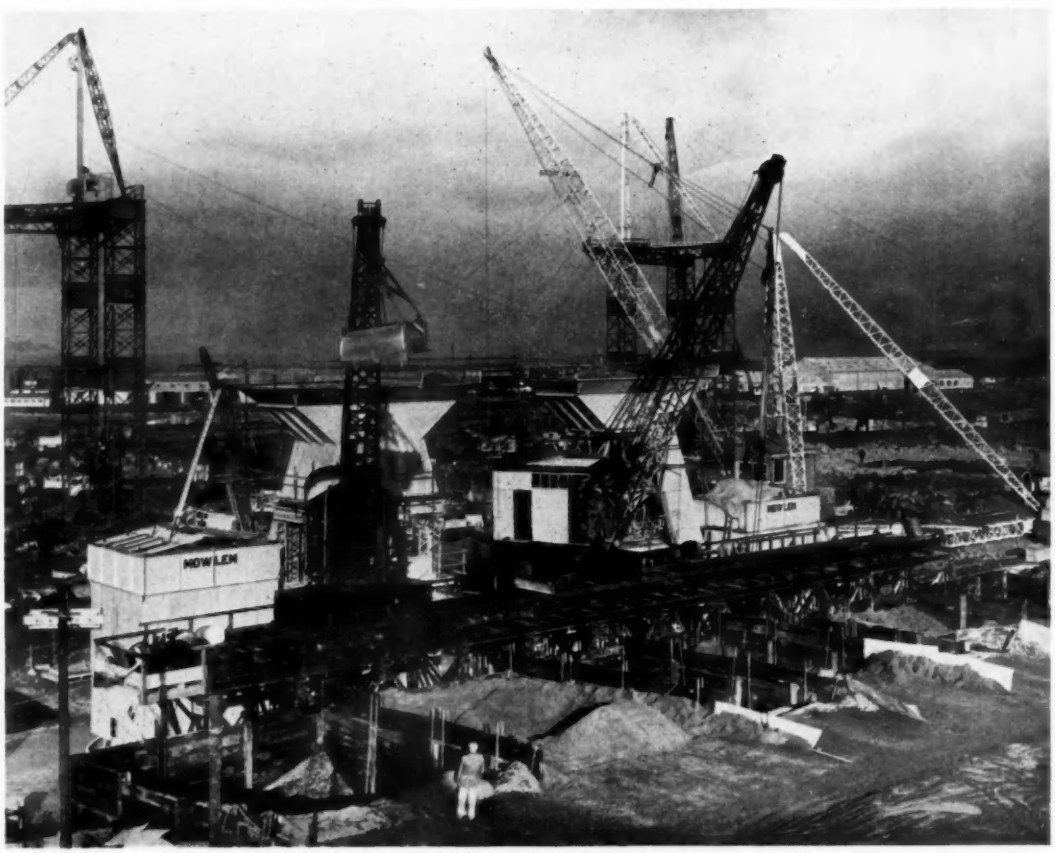

Fig. 3.—Concrete batching plant alongside the site of Reactor "A".

the cooling-water inlet culverts. To eliminate the need for blasting in the vicinity of the first reactor once the structural concrete has been placed, the excavations for the irradiated-fuel storage pond have also been completed. However, as this area will be required for precasting the heavy concrete beams of the reactor building, the loose rock has been replaced for the time being.

In preparation for the cooling-water inlet and outlet works, a series of boreholes has been sunk off the coast, and others are still being made.

The presence of a rock base very near the surface is a most valuable asset for the foundations of the heavy structures, but may introduce slight difficulty in connection with sewers and drains. Particular attention has therefore had to be given to the planning and phasing of this work, but most of the necessary blasting has now been finished. Surface-water drainage has been a problem owing to the large quantities involved, but a 21 in. main drain has been installed to meet this requirement.

To ensure that the civil engineering activities can continue unhindered by work on the main steel structures, a complete workshop and prefabrication apron are provided on site. The workshop is a twin-bay, steel-framed building served by two 40 ton travelling cranes. It is designed so that four steam-raising units, each 80 ft. long and 20 ft. in diameter, can be assembled simultaneously. The apron in front of the workshop will be used for the prefabrication of the six tiers of each 70 ft. dia. spherical reactor pressure vessel before lifting them into their final position.

GOLIATH CRANE.

The workshop and apron are located on the centre-line of the two reactors so that the Goliath crane, which will be used for raising and placing the steam-raising units and pressure-vessel sections, will pass over these construction areas. This crane, which will be the outstanding piece of constructional equipment employed on the site, will have a height and span of 200 ft., so that it can straddle a completed reactor building, and will be capable of lifts up to 350 tons. The massive prefabricated sections of the crane legs (fig. 2 and 4) have been assembled on site and the work of erection is now well advanced.

Much work has been involved in the provision of temporary buildings and services. An 11 kV electrical distribution system has been installed and is being extended, as required, to allow for an expected total capacity of 10 MVA. One rather unusual load on this system is a 500 kW heater in a 12,000 gallon water tank which supplies the concrete batching plant (fig. 3). This heater raises the temperature of the water almost to boiling

Fig. 4.—Two of the crane legs after erection.

point so that concreting can continue even in conditions of slight frost.

Among the other temporary buildings which have been completed there are several well-heated stores, and also a well-equipped small workshop with facilities for manufacturing practically any small machine components or fabrications.

MATERIAL REQUIREMENTS.

Some idea of the magnitude of the task which confronts the various contractors can be gathered from the quantities of materials required. For example, the preparatory work alone involved the excavation of more than 160,000 cu. yd. of soil and rock.

Unusually large quantities of concrete are required in the construction of nuclear power stations of this type, mainly for the massive concrete shields which surround the reactor cores. In this station, each reactor pressure vessel will be surrounded by reinforced concrete walls, 9 ft. thick, and with a 10 ft. 6 in. roof above. It is estimated that a total of 200,000 tons of concrete will be poured during the construction of the power station.

Each of the 70 ft. dia. reactor pressure vessels, which must withstand an internal gas-pressure of 150 lb. per sq. in., will be welded from steel plate up to 3 in. thick, the total weight of the complete sphere being nearly 1,000 tons. Further large quantities of steel plate are required for the cylindrical pressure vessels enclosing the sixteen steam-raising units, each of which will be 19 ft. 6 in. in diameter, 73 ft. 6 in. in overall height, and will weigh 210 tons. Approximately 14 miles of mild steel tubes, all with specially designed finned surfaces, will be assembled inside each of these vessels under conditions of scrupulous cleanliness.

The reactor cores themselves will be approximately cylindrical in shape, and will be some 50 ft. 6 in. in diameter and 28 ft. in height including the graphite reflectors which will surround the moderator proper. Each core will be built up from more than 2,000 tons of machined graphite bricks and tiles which will have to be positioned to a very fine degree of accuracy in order to obtain correct alignment of the 3,288 vertical fuel channels. Once again, conditions approaching those of surgical cleanliness will be maintained during the erection of the core.

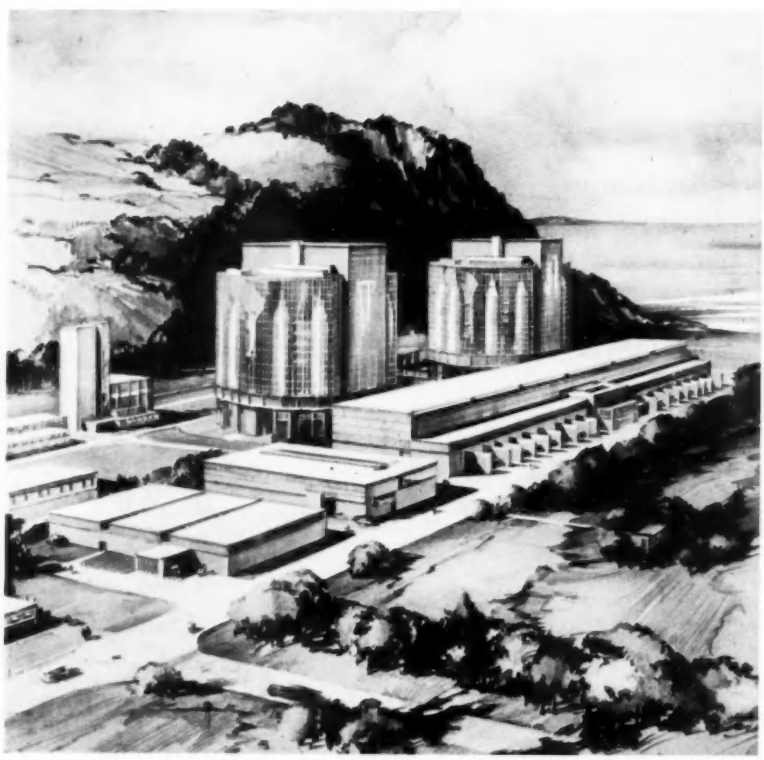

Fig. 5.—An artist's impression of the completed power station.

Some Aspects of the Electrical Design of Universal Motors

By G. W. BINGHAM, B.Sc., A.M.I.E.E.,
Fractional Horsepower Motor Works, Witton.

With its ability to operate on d.c. or on a.c. over a wide range of frequencies, the universal motor is an essential part of much domestic and industrial equipment. The author defines the field of application governed by its horsepower and speed range. His review of design problems, with particular reference to commutation, includes considerations affecting the choice of brushes and a method of finding the brush position for best commutating conditions.

UNIVERSAL motors have three outstanding advantages compared with induction motors: (1) they can be used on both d.c. and a.c. supplies; (2) they can be made for operation at any speed within very wide limits, and (3) they are suitable for a wide range of speed control. They cannot compare on price, however, with the induction motor for operations within the latter's capabilities. Their characteristics make them suitable for many domestic appliance applications and, while d.c. supplies are becoming fewer, these motors can be used over a wide range of frequencies on a.c. supplies, it being quite common for them to be operable on d.c. and on a.c. at any frequency up to 60 c/s. They are an essential part of equipment, both domestic and industrial, with a production worth many million pounds a year in this country alone.

GENERAL ASPECTS.

The universal motor (fig. 1) is a series wound, commutator machine suitable for use on both d.c. and a.c. single-phase supplies and entirely confined to small fractional horsepower sizes, particularly in appliances such as vacuum cleaners, floor polishers, hair dryers and portable drills. The motors are made for outputs up to about 0·5 h.p., but are very seldom used in larger sizes owing to the serious commutation problem.

The universal motor is at its best as a high-speed machine, i.e. when running at about three times synchronous speed, when the power factor is near to unity and the performance is similar on both a.c. and d.c. supplies at the same voltage. Speeds of about 9,000 to 11,000 r.p.m. are quite usual in vacuum cleaners. The motor is not ideal at speeds below synchronous on a.c., though it can be made quite successfully to operate down to half this speed or even lower.

The difficulty in the low speeds is due to the rapid drop in the torque/speed characteristic resulting from the highly inductive windings required for low-speed working, as both field and armature have a large number of turns. Only a slight increase in load can cause a large fall in speed, and even stalling (fig. 2). The discrepancy between the performances on d.c. and a.c. becomes very pronounced on such multi-turn windings, and so it is necessary to design for a.c. and add extra field turns for d.c. (fig. 1b). As the effect is due to highly inductive windings, it is obviously worse on high frequencies than on low, so that the discrepancy between low-speed performance on a.c. supplies of different frequencies is also very pronounced.

As the induction motor can rival the universal machine for most applications where the speed is 2-pole synchronous or less, and is much cheaper, the lower limit of the universal motor tends to become about 3,000 r.p.m., except for special purposes. The upper limit in speed is probably about 20,000 r.p.m., and here the limit is due to commutation and bearing difficulties. Due to these problems, machines running at speeds above 10,000 r.p.m. have short time rated duties so that carbon brush and bearing wear is not too rapid, e.g. the domestic appliances previously mentioned do not run for long periods nor very often, and this discontinuous duty relieves the problem of brush and bearing wear.

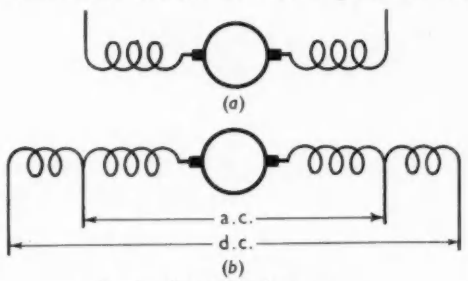

Fig. 1.—Connection diagrams.

At about five times synchronous speed and above it is possible for the power factor to become leading. Comparatively few turns are required in the windings at these high speeds and the inductive volt-drops are much reduced. A study of the vector diagram (fig. 4) shows that low values of the volt-drops give quite a high armature back e.m.f., E_r, which can make the current I lead the voltage V, though not by very much.

The design of this machine is essentially that of the a.c. series motor, as it is an easy matter to cater for extra field turns for the d.c. working condition when required, this being necessary only on lower speed designs, i.e. below twice synchronous speed. Compensating windings are used on larger a.c. series motors but very seldom on small universal motors, and their use therefore is not considered here.

As commutation is one of the most difficult aspects of this type of motor, every effort must be directed

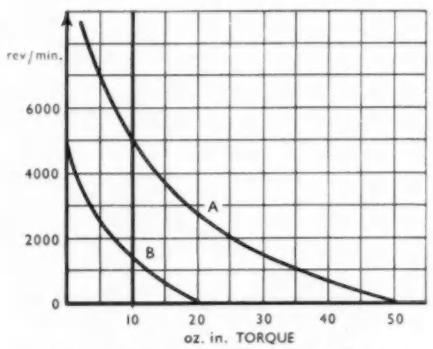

Fig. 2.—Torque/speed characteristics.

to making conditions as easy as possible. To do this, the number of turns per coil under commutation is made as small as possible, which means having a large number of segments, slot permeances being kept low (i.e. shallow wide slots, large slot openings, commutation in the inter-polar space, short-pitched coils, etc.) ; but all these aspects are balanced against other requirements, e.g. large slot openings mean an increased Carter coefficient, wide slots possibly mean increased armature diameter, and a large number of segments means a costly winding. All attempts to keep commutation difficulties within reasonable bounds affect the cost of the machine very sensitively.

Examination of the problems discussed later, in the section on commutation, will show how the various parts and conditions affect the resultant voltage of commutation, and, as they have no compoles or compensating windings, it can be understood how much these little motors depend on good quality carbon brushes. It is a remarkable tribute to the carbon brush manufacturers that their products stand up so well to the very arduous conditions to which they are submitted in universal motors.

On cheaper products, where armatures with a small number of slots and segments are used, the sum of reactance and transformer voltages across the commutating coil might be as high as 12 to 14 volts peak ; this is resisted by the brush contact drop to some extent, but the brush would be asked to cope with it and at the same time not to have too high a coefficient of friction, so that the temperature rise on a fast running commutator is not excessive.

The excellence of the carbon brush manufacturers' products is a big factor in the success of universal motors. Careful selection of the right brush for the job is most essential, and considerable time is devoted to testing to find the most suitable grade.

On account of the high speeds, small eccentricities or discrepancies in true running of the commutator can be serious, causing brush bouncing. Therefore spring pressures are kept high, sometimes up to 6 lb. per sq. in. on higher speed machines, and care is essential in choosing brushes with a suitable friction coefficient.

With undercut micas noise can be a nuisance and in many cases flush micas are used, but again care is required as the micas must wear with the copper or they will become proud, causing destructive sparking from a bouncing brush. The brush must, in these conditions, be capable of wearing down the mica as well as meeting its other problems.

Commutation must take place as far as possible while the short-circuited coil is passing through the inter-polar space in order to minimise the reactance voltage. This calls for very careful selection of the armature coil connection to the commutator as the brush box is usually fixed to the frame and no adjustment is possible. The best position for this connection being very critical on a.c. working, especially on slower speed motors, only a small tolerance can be allowed on the positioning of the commutator bars relative to the slots.

The armature core stampings are usually assembled so that the slots are skewed about 1 slot pitch. This tends to reduce the variation of the reluctance of the main flux circuit through the armature and reduces noise which could easily be caused by sudden changes of magnetic flux.

The design of the armature is similar to a normal d.c. type, but the stator for the field system, though having salient poles, must be built of laminations to suit alternating flux conditions. Many of these stators are now suitable for machine-winding of the field coils, and this must be borne in mind when shaping the pole shanks.

The iron parts of the flux circuit should not be saturated as this means a large number of turns for excitation and turns must be kept to a minimum ; hence a small air-gap and large iron sections are required. High densities will lead to noise, as on all a.c. machines.

Owing to necessary production tolerances there are bound to be many machines with some eccentricity of the armature in the stator bore. This must be kept to a minimum, for the lateral pull on the armature will be stronger on the small gap side so that, with an

alternating flux, there will tend to be hammering on the bearings. This tendency is much more pronounced on 4-pole than on 2-pole machines as the gap densities can have much larger discrepancies.

To cater for any extra forces the bearings should be of ample area, with adequate lubrication.

DESIGN ASPECTS.

Main Problems of the A.C. Design.

Having estimated the physical sizes of the iron circuit to suit a chosen value of main flux with reasonable densities, such as a B max. of about 13,000 Maxwells/sq. cm. in good quality electrical sheet steel, there are four main problems to be examined.

(1) The inductive effects in the various parts of the windings.
   - (*a*) E_F, the transformer voltage generated across the field coils by the main flux.
   - (*b*) E_A, the transformer voltage generated across the armature winding by the main flux.
   - (*c*) E_C, the transformer voltage generated across the armature commutating coils by the main flux.
   - (*d*) X_F, the leakage reactance of the field winding.
   - (*e*) X_A, the leakage reactance of the armature winding.

(2) Construction of the vector diagram, from a selected winding and a chosen value of main flux. The armature back e.m.f. E_r is finally obtained.

(3) From the value of E_r in (2), the speed and torque are calculated from the appropriate formulae.

(4) A study of the commutating conditions is made, with calculations of the reactance and transformer voltages.

1(*a*) *Field Transformer Voltage* E_F.

The back e.m.f. induced across the field winding will be, assuming sinusoidal flux form,

$$E_F = 4{\cdot}44\, f\, N_F\, \Phi_M\, 10^{-8} \text{ volts.}$$

This voltage will lag Φ_M by 90°, hence the component of the applied voltage to supply this will be $-E_F$ shown in the vector diagram, and this leads Φ_M by 90°.

(*b*) *Armature Transformer Voltage* E_A.

If the armature cross-field magnetic axis is at 90° to the main field axis, then the number of armature turns to the right of the main-field axis is the same as the number of armature turns to the left, and the resultant transformer voltage generated across the armature is zero as the voltages induced in the right and left parts cancel.

If, however, the armature cross-field axis is shifted, either by movement of the brushes or by connection of the coils to commutator segments further round, then there will be a greater number of coils in the arc between the main flux axis and the armature cross-field magnetic axis in the direction of movement of the brushes than in the opposite direction and a resultant transformer voltage will appear at the armature terminals. Carrying this movement so far that the armature cross-field magnetic axis lies along the main flux axis, then all the armature coils are traversed by the main flux and the transformer voltage would be similar in expression to that for the field turns, E_F, except that $\frac{N_A}{2a}$ would replace N_F.

It is evident that this transformer voltage varies according to the position of the armature cross-field

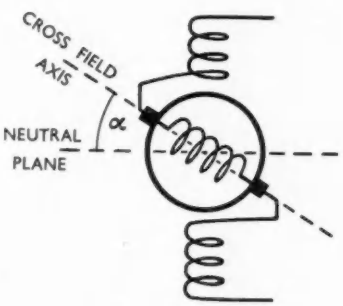

Fig. 3.—Cross-field axis.

axis, and (α being the angle between this axis and the neutral plane) E_A will vary as sin α (fig. 3), and so we have $E_A = 4{\cdot}44\, f \frac{N_A}{2a}\, \Phi_M \sin \alpha\, 10^{-8}$ volts.

Again E_A lags Φ_M by 90° and so $-E_A$ will lead, and be in phase with $-E_F$.

(*c*) *Commutation Transformer Voltage,* E_C.

The armature coils undergoing commutation are in such a position, for best operating conditions, that they embrace the main flux Φ_M so that a transformer voltage is induced in these short-circuited coils.

Again, it will be influenced by angle α, but as the coil embraces maximum flux area when α is zero and minimum when α is 90°, the commutating coil transformer voltage will be

$$E_C = 4{\cdot}44\, f\, N_C\, \Phi_M \cos \alpha\, 10^{-8} \text{ volts,}$$

where N_C is the number of turns in the coil undergoing commutation.

Again this voltage, will lag Φ_M by 90° and so $-E_C$ will be in phase with $-E_F$, $-E_A$.

There is, however, a further consideration regarding this voltage, because it exists in a closed circuit and therefore produces a current I_C which must be accounted for in the vector diagram.

The value and phase of this current depends on the resistance and reactance of the commutating coil so that

$$I_C = \frac{E_C}{Z_C}, \text{ where } Z_C = \sqrt{R_C^2 + X_C^2}$$

and lags E_C by the angle ϕ_c, where $\cos \phi_c = \frac{R_C}{Z_C}$.

For allocating to the current vector, I_C must be multiplied by the transformation ratio

$$\frac{N_C}{2N_P}, \text{ so } -I'_C = I_C \frac{N_C}{2N_P},$$

and for ζ coils undergoing commutation at the same time $-I_C$ will be ζ times as large.

The vector is applied in direction from the end of the iron loss vector I_i.

As this transformer loss can be very severe, it is necessary to keep N_C low which, for a given value of N_A, means dividing the armature winding into as large a number of sections as possible and hence a large number of commutator segments.

LEAKAGE REACTANCE.

(*d*) *Field Coils, X_F.*

There are five main leakage paths :

(1) Pole sides to yoke through the coil.
(2) Pole tips to yoke.
(3) Pole tips to adjacent pole tips, through air.
(4) Pole tips to adjacent pole tips, across armature surface.
(5) End windings.

The permeance and inductance calculations are made for each section, and the sum of the five inductances gives the full field leakage inductance, L_F, and $X_F = 2\pi f L_F$ ohms.

(*e*) *Armature Winding, X_A.*

Here again there are five main leakage paths :

(1) Cross-field path.
(2) Across the slots.
(3) Armature surface to pole face.
(4) Armature surface in interpolar space.
(5) End windings.

The sum of these five inductances give the full armature leakage inductance, L_A and $X_A = 2\pi f L_A$.

The total machine leakage reactance is X, where $X = X_F + X_A$ and the reactance drop $= IX$.

These reactance calculations are of great importance and it is necessary to get as accurate an estimate as possible of them. The ten reactance calculations are quite prolonged and tedious so it is not intended to go into them in this general survey but they will be the subject of a further article.

It will be seen, by a study of the reactance volt drops, that the larger they are the lower will be the power factor and the rotational e.m.f. E_r. Since the power output is proportional to E_r, the reactance values should be kept low.

As all the values include some figure of (turns)^2, it is important to keep the turns as low as possible ; this means using large iron sections and keeping the main flux as high as possible; also, leakage in air is reduced by long air paths, but both these tendencies mean a large machine with consequent expense. Also, as mentioned before, the turns/coil, N_C, can be kept down by having a large number of segments, but again with consequent expense.

THE VECTOR DIAGRAM.

In phase with the main flux vector Φ_M is the magnetising current vector I_m to a chosen current scale.

The value of I_m is such that the field ampere-turns $I_m N_F$ provide the excitation for flux Φ_M. The iron loss current I_i in phase with $-E_F$, is drawn from the end of I_m. From the end of I_i, the current due to transformer action on the short-circuited coils $-I'_C$ is drawn to scale and at appropriate angle.

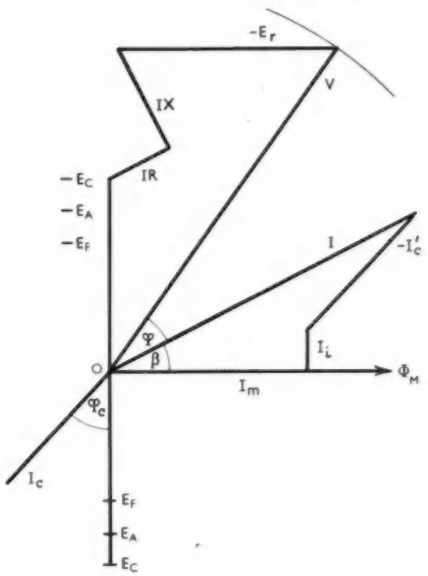

Fig. 4.—Vector diagram.

The total line current I is the vector joining O to end of $-I'_C$. The voltage vectors E_F, E_C and E_A are drawn 90° lagging on Φ_M and the components of the main supply voltage vector V must be drawn at 180° from these, $-E_F$, $-E_C$ and $-E_A$. As they are all in phase they are directly additive.

The resistance drop IR, where $R = R_A + R_F$, is drawn from the end of $-E_A$ and parallel to current vector I.

The leakage reactance drop IX, where $X = X_A + X_F$, is drawn from the end of IR and at right angles to the IR vector.

The final component is $-E_r$, the e.m.f. induced in the armature winding due to rotation, and this must close the voltage vectors to the supply voltage vector V. As the rotational e.m.f. E_r is in antiphase with the main flux Φ_M, then $-E_r$ is parallel to Φ_M. Drawing a circle of radius V and drawing $-E_r$ from end of IX, and parallel to Φ_M till it cuts the circle of V will give the vector $-E_r$ in magnitude and direction. OV is the supply voltage V.

The angle ϕ between vectors V and I, is the angle of lag of the current, and the power factor is $\cos \phi$.

This is the vector diagram for one condition of

loading, the selected value of flux Φ_M finally giving current I and the rotational e.m.f., E_r.

Speed, n, can be readily calculated, from the value of E_r.

A new vector diagram must be drawn for each selected value of Φ_M.

Examination of the diagram shows that the smaller the induced voltages E_F, E_C, and E_A, and also the IR and IX volt drops, then the larger E_r becomes, tending towards value V at the I_m axis.

Power output is proportional to E_r. At very high speeds, when N_F and N_A are low, it is possible to have vector V so far round towards Φ_M that I becomes leading, especially if the Φ_M iron loss I_i is relatively large.

At the other end of the scale, the stalled condition is met when the IX vector meets the circle of V, then E_r is zero.

Rotational e.m.f. E_r Formula.

The voltage induced across the ends of a coil rotating in a magnetic field is

$$e_r = -k\omega\Phi \sin\theta$$

where k is the ratio $\frac{f_n}{f}$ $\left(\begin{matrix} f_n = \text{speed frequency} \\ f = \text{supply frequency}\end{matrix}\right)$

Φ the instantaneous flux value, and θ is the instantaneous position of the coil measured as an angle from the mid inter-polar plane to the plane of the coil.

As $\Phi = \Phi_M \sin\omega t$

$e_r = -k\omega\Phi_M \sin\omega t \sin\theta$ for a single turn coil.

Extending this to a wound armature with $\frac{N_A}{2a}$ turns distributed over the armature surface per armature circuit, and the axis of commutation being at angle α from the inter-polar neutral plane,

$$e_r = -\frac{N_A}{2\pi a} k\omega\Phi_M \sin\omega t \int_{\alpha}^{\pi+\alpha} \sin\theta \, d\theta$$

$$= -\frac{1}{\pi a} k\omega N_A \Phi_M \sin\omega t \cos\alpha.$$

The average value of the e.m.f.

$$= -\frac{1}{\pi^2 a} N_A k\omega\Phi_M \cos\alpha \int_{o}^{\pi} \sin\omega t$$

$$= -\frac{2}{\pi^2 a} N_A k\omega\Phi_M \cos\alpha$$

and the r.m.s. value

$$E_r = -\frac{1}{\sqrt{2}\,\pi a} N_A k\omega\Phi_M \cos\alpha \; 10^{-8} \text{ volts}$$

The negative sign shows it to be opposite in phase to the main flux.

$$\text{As } N_A = \frac{Z}{2} \text{ and } k\omega = \frac{2\pi np}{60}$$

$$E_r = -\frac{Zn\,\Phi_M\,p}{\sqrt{2}\,60\,a} \cos\alpha \; 10^{-8} \text{ volt}$$

Torque Formula.

The power into the rotor will be the product of the two components of voltage and current which are in phase with Φ_M, and these are E_r and $I\cos\beta$, where β is the angle between I and Φ_M vectors. So the watts input to rotor, less the copper loss, is

$$W_r = E_r\, I \cos\beta \text{ watts}$$

$$= \frac{Zn\,\Phi_M\,p}{\sqrt{2}\,60\,a} I \cos\beta \cos\alpha \; 10^{-8} \text{ watts}$$

so torque $T_r = \frac{33000}{2\pi\, n} \frac{Zn}{746} \frac{\Phi_M\, p\, I}{\sqrt{2}\,60\,a} \cos\beta \cos\alpha \; 10^{-8}$ lb. ft.

$$= 16 \frac{p}{a} Z\,\Phi_M\, I \cos\beta \cos\alpha \; 10^{-8} \text{ oz. in.}$$

Note that this is the torque calculated from the input to the rotor, and to obtain the output torque the rotational loss torques must be subtracted from it, i.e. those for rotational iron loss, carbon brush friction, bearing friction and windage.

Reactance Voltage due to Commutation.

The current per conductor follows the sine wave value up to the moment B when commutation of a particular coil commences (fig. 5a).

The current reverses from B to D during the time of commutation, which ends at t_2 when the current has the value it would have had at C but reversed, as at D.

Maximum value of conductor current $= I_M$
Instantaneous value of conductor current $= i$
Instant in time when commutation commences $= t_1$
Instant in time when commutation ends $= t_2$
Current in coil follows wave form.

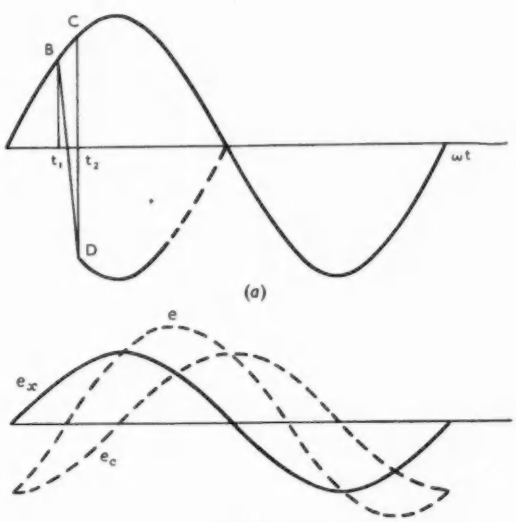

Fig. 5.—Commutation during current wave (a), and voltages of commutation (b).

$i=I_M \sin \omega t$ up to point B when it changes to a linear form $i=a\ t+C$ where a and C are constants, during the time (t_2-t_1). Starting time t from time t_1 then $t=0$ at time t_1 so $i=C$, hence

$C=i=I_M \sin \omega t_1$

a=gradient of the line

$$=\frac{-(I_M \sin \omega t_1+I_M \sin \omega t_2)}{\omega(t_2-t_1)}$$

If b=brush width arc, cm.

m=mica thickness arc, cm.

v_c=commutator peripheral speed, cm./sec.

Time of commutation.

$$t_2-t_1=\frac{b-m}{v_c}$$

$$\text{so } a=-\frac{(I_M \sin \omega t_1+I_M \sin \omega t_2)}{\omega \dfrac{b-m}{v_c}}$$

Formula for current during straight line commutation is

$$i=I_M \sin \omega t_1-\frac{I_M\ (\sin \omega t_1+\sin \omega t_2)}{\omega\ \dfrac{b-m}{v_c}}\ \omega t$$

The m.m.f. of the coil due to i

$$M=\frac{4\pi}{10}\ I_M\ T_c\left[\sin\ \omega t_1-\frac{\sin \omega t_1+\sin \omega t_2}{\dfrac{b-m}{v_c}}t\right]$$

If P=permeance of the leakage flux circuit,

Leakage flux $\Phi_L=M\times P$

P will consist of 2 slot and 2 overhang permeances

$\Phi_L=M\ (2P_s+2\ P_o)$

Linkages

$$\mathcal{L}=(2\ P_s+2\ P_o)\ \frac{4\pi}{10}\ I_M\ T_C{}^2\left[\sin \omega t_1-\frac{(\sin \omega t_1+\sin \omega t_2)}{\dfrac{b-m}{v_c}}t\right]$$

and reactance voltage

$$e_x=\frac{d\mathcal{L}}{dt}\ \ 10^{-8}$$

$$e_x=-(2P_s+2P_o)\ \frac{4\pi}{10}\ I_M\ T_C{}^2\ \frac{\sin \omega t_1+\sin \omega t_2}{\dfrac{b-m}{v_c}}10^{-8} \text{ volts.} \qquad (1)$$

Transformer Voltage of Commutation.

The instantaneous voltage induced in the commutating coil due to transformer action—

$$e_c=-\frac{d\Phi}{dt}N_c \cos \alpha=-N_C \cos \alpha\ d\ \frac{[\Phi_M \sin\ (\omega t_1+\omega t-\partial)]}{dt}$$

Where $\Phi \cos \alpha$ is the proportion of Φ which passes through the coil, angle α the same as explained in earlier section, and ∂ is the angle of lag of the flux behind the current i due to hysteresis.

$$e_c=-2\pi\ f\ N_C\ \Phi_M\ \cos \alpha\ \cos\ (\omega t_1+\omega t-\partial)10^{-8} \text{ volts.} \qquad (2)$$

This is a negative cosine wave having a maximum value of $2\pi\ f\ N_C\ \Phi_M \cos \alpha$.

The r.m.s. value will be this maximum value divided by $\sqrt{2}$ and so gives—

$$E_C=4{\cdot}44\ f\ N_C\ \Phi_M \cos \alpha\ 10^{-8} \text{ volts,}$$

the formula given in the earlier section on this commutation transformer voltage.

Resultant Commutation Voltage.

Having established the two instantaneous voltage equations e_x and e_c, it is only necessary to take the sum of these to find the resultant voltage across the coil.

e_x will be maximum when $\dfrac{de_x}{dt_1}=0$

and this gives $\cos \omega t_1=-\cos\ (\omega t_1+\theta)$ and this occurs when $\omega t_1=\dfrac{\pi}{2}-\dfrac{\theta}{2}$, θ being the electrical angle turned through during time of commutation.

Now e_c will be a maximum when $\dfrac{de_c}{dt_1}=0$ and this gives $\omega t_1+\omega t-\partial=0$.

As ωt, δ, and $1/2\ \theta$ are small angles, the above voltages e_x and e_c are practically 90° out of phase.

Now e_x is trying to maintain the current wave so, with reference to that wave, is a positive sine wave, while e_c is a negative cosine wave.

Resultant Voltage.

$e=e_x+e_c$ (fig. 5b) and from equations (1) and (2) above it is seen that

e is proportional to $\sin \omega t_1 - \cos \omega t_1$

and that is, to $-\sqrt{2} \sin\left(\omega t_1+\dfrac{3\pi}{4}\right)$

so the resultant wave will be a sine wave 135° in advance of position t_1 (the beginning of commutation).

i.e. maximum value occurs when

$$\omega t_1+\frac{3\pi}{4}=\frac{\pi}{2} \text{ or } \frac{3\pi}{2}$$

$$\text{i.e., } \omega t_1=-\frac{\pi}{4} \text{ or } +\frac{3\pi}{4}$$

Therefore to obtain the worst voltage condition in the short circuit coil it is only necessary to calculate, at the commutating time $\omega t_1=135°$, the values of e_x and e_c and add them.

Pitch of Armature Coils.

Full pitch armature coils are seldom used for two main reasons.

(1) Both coil side groups in one slot are undergoing commutation at the same time and the mutual inductance causes greater leakage flux and hence a higher reactance voltage of commutation.

(2) The overhang length is longer than a shorter pitch coil and so a saving of copper is made on the latter. Very little effect is made on performance provided the short pitching is not too severe.

This pitching must be watched with reference to the brush width, as short pitching reduces the available arc of commutation.

It is usual to short pitch the coil throw by one slot for even slotting, or, what is perhaps a better selection, use

an odd number of slots, and pitch the coil throw to the slot just short of full pitch.

An odd number of slots is useful in that it tends to keep the main flux circuit reluctance more constant as the armature rotates than an even number does.

CARBON BRUSH.

The section should be chosen bearing in mind the full current in the brush due to the input current and the commutating currents, and a value of current density should be used which gives an easy rating to the brush.

Maximum values are given by the brush manufacturers to suit the conditions of working and these values should not be exceeded.

The width of the brush should be such that commutation does not take place while the coil is under the pole arc, and this means that the brush arc must not be greater than (the mean winding arc, less the pole arc, less the skew) for 1 coil per slot.

For 2 coils per slot, the brush arc must not be greater than (the mean winding arc, less the pole arc, less the skew, less one segment arc).

This usually means that the brush width is narrow on this type of machine and, although it reduces the time of commutation and hence keeps the reactance voltage up on that account, it keeps the number of coils undergoing commutation at any instant down, which is much more important.

As these machines usually rotate at fairly high speeds and the brushes require up to 6 lb. per sq. in. or so pressure, there should not be a high coefficient of friction between brush and commutator, or overheating may result. A compromise must often be made as the brushes that can best deal with severe voltage conditions sometimes have a fairly high value of μ and advice from suppliers is recommended.

It is probably unfair to quote wear rates, as conditions can vary so very greatly on different designs and applications, but rates of wear up to 0·001 in. per hour can take place under difficult high speed conditions on continuous running. As it is probably possible to have a brush depth when new of perhaps only 0·4 in. on a small machine, the life of the brush would be only 400 hours. However, as stated before, this type of machine is very seldom used on continuous duty, so that the 400 hours covers a considerable period of time for applications having only intermittent use, and such rates of wear can be acceptable.

COMMUTATOR CONNECTIONS.

The brushgear being usually a fixture in the frame or bracket, it is not possible to make adjustments to the brush position on test as can be done on large machines, so it is essential for the brush position, for best commutating conditions, to be assessed in the design stage. A useful way of checking this is to draw out, preferably on squared paper, the armature winding diagram, keeping the disposition of the slotting and skewing, if any, to some chosen scale.

The two lines forming the commutator are also drawn in at some convenient distance from the core, but the segment separation lines, i.e. micas, are not yet put in.

Then, on tracing paper, the poles and brushes are marked in to the same scale and in such positions that the poles lie over the armature core and the brush edge lies on the edge of the commutator, when the tracing paper is placed over the winding diagram. The tracing paper is then moved over the winding diagram till the neutral position is obtained.

If neutral is required, the mica positions are marked in on the commutator in the correct places. If the machine is for a fixed direction of rotation, then some allowance can be made for armature reaction effect by making the commutating position at a small forward angle. To allow for this the commutator leads are connected to the commutator bars which make the selected angle from the neutral, further round in the direction of rotation.

This angle could be as much as 20° (electrical) or more on a heavily loaded, high-speed armature. The tolerance that can be allowed on the exactness of this position might be about $\pm$ 6° but on a slow-speed machine, say, about synchronous speed, the forward allowance of lead would be only about 10° and the tolerance much tighter, probably $\pm 3°$.

If brushes on a rocker can be used, the tolerances to which the commutator lead should be set are relaxed but usually the cost of carrying brushes on a rocker is large compared with the simple arrangement of fixed boxes.

A fair amount of tolerance on performance would have to be allowed when such commutator lead tolerances are not possible.

CONCLUSION.

The foregoing are some of the problems met with in the electrical design of a universal motor. There are others, such as iron losses in the armature, leakage reactances, etc., which would need to be treated in a separate article.

LIST OF SYMBOLS.

Φ_M	Maximum value of main flux.
N_F	Total number of turns on field system.
N_P	Total number of turns per pole.
N_A	Total number of turns on armature.
N_C	Number of turns per armature coil.
Z	Total number of armature conductors.
L_i	Core length (cm.).
α	Electrical angle of plane armature cross field to the neutral plane midway between the poles.
f	Supply frequency.
f_n	Rotational frequency.
k	ratio $\frac{f_n}{f}$.
$2p$	Number of poles.
$2a$	Number of armature circuits.
ζ	Number of coils undergoing commutation under all brushes at any instant.
n	Speed, r.p.m.

New Trolleybuses in Glasgow

Fig. 1.—One of the new vehicles in service.

THIRTY of the new trolleybuses (fig. 1) recently placed in service by the Glasgow Corporation Transport Department have been supplied with traction equipment by the G.E.C. The power scheme incorporates the Company's patent "I.R. Control" system, which provides rheostatic braking with protection against over-torque and virtual independence of motor temperature, so that high braking efforts may be used safely in service. At the same time the braking effort is well maintained over a wide range of speeds. The buses are also equipped for automatic acceleration.

A single compound-wound motor of 125 h.p. is installed. While motoring, the separately-excited shunt field is connected through its discharge resistance across the main resistance, so that the effect of this field is reduced progressively as the main resistance is eliminated, and on completion of the resistance notching it is short-circuited. Six resistance notches are provided with the use of only five contactors by arranging for series-parallel connection of resistance sections on certain steps. Three weak-field notches are formed by two steps of field diversion and then by tapping one section of the series field.

Automatic control of acceleration is effected by an oil dashpot associated with the master controller, and under the influence of a relay carrying motor current. Since the master controller is connected to the pedal by a spring drive, it will follow pedal movement only if free to do so. The oil retarder has two valves, the main valve being controlled by the relay carrying motor current. So long as the motor current is below a predetermined value, the relay will drop and open the main valve, allowing the master controller to follow the pedal. Any rise in current will close the valve immediately and arrest the controller progression. To avoid stalling on hills or in other circumstances, the second valve associated with the oil retarder allows the master controller movement to follow that of the pedal at a slow rate, regardless of the current control of the main valve.

For rheostatic braking the power circuits are arranged so that only a portion of the series field winding remains in circuit and the regenerated current flows through it in the reverse direction to normal motoring. Referring to the simplified diagram, fig. 2, it will be seen that a braking circuit is formed through the armature, the braking resistor *B* and the series field winding *C*. The speed-brake characteristic with this arrangement alone would not be suitable, but it is so designed that, at maximum build-up, it will not produce sufficient braking torque to damage the transmission although it may exceed a safe continuous running torque. This is necessary

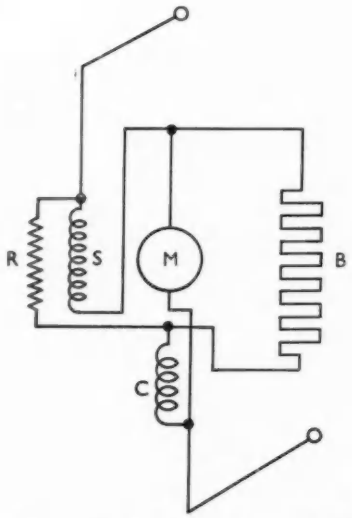

Fig. 2.—Simplified diagram of "I.R." circuit for braking.

to avoid damage to the transmission in the rare event of failure of the regulating shunt field *S*.

The regulating shunt field winding *S* is energised in series with the motor armature across the line. Thus, when the voltage of the armature *M* is high, at high-speed braking, the armature voltage will exceed line voltage and create inverse excitation. At low speeds the excitation will be cumulative due to the line voltage exceeding the armature voltage. This results in a more constant braking effort curve than was obtained in older systems, which is an advantage to the driver. The scheme in the new Glasgow buses incorporates the latest method developed by the Company for switching off the motor shunt field, which takes place at approximately ½ m.p.h.

Should the trolley leave the line, the discharge resistor *R* will maintain sufficient energisation of the separately-excited field winding at high speeds to maintain the high-speed performance part of the characteristic reasonably the same. Some falling off of effort will, however, result at lower speeds.

The buses are equipped for battery manœuvring, this facility being obtained by means of a changeover switch. The battery is charged by an L.T. generator overhung on the motor (fig. 3).

Visible and audible warnings of dewirement are provided, a loss of supply causing two indicator lamps to be extinguished and a relay to be released which energises a buzzer from the L.T. circuits.

The butt contact master controller and the contactor equipment case are cab-mounted, the latter being of a new design. All-metal construction has been adopted for the contactor case (fig. 4), which has a double-hinged cover arranged to fold back in two sections and to be held open by a strut in a convenient position for unobstructed access to the interior. Resilient mountings ensure freedom from the effects of shocks transmitted from the road wheels.

The master controller is illustrated in fig. 5. It is of the silver butt contact type and is so designed that the actuating mechanism does not involve any gearing.

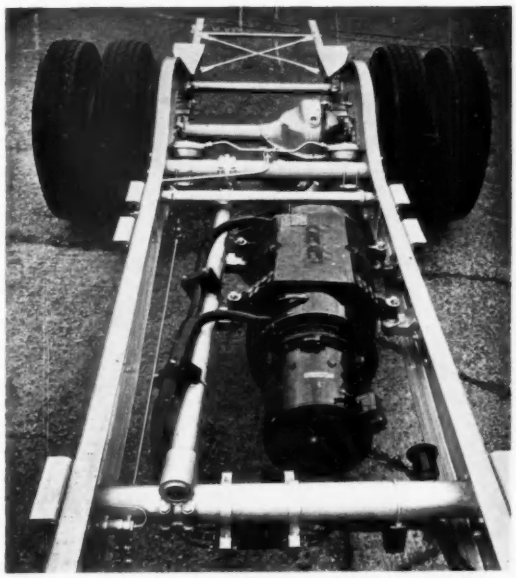

Fig. 3.—The 125 h.p. motor with overhung auxiliary generator.

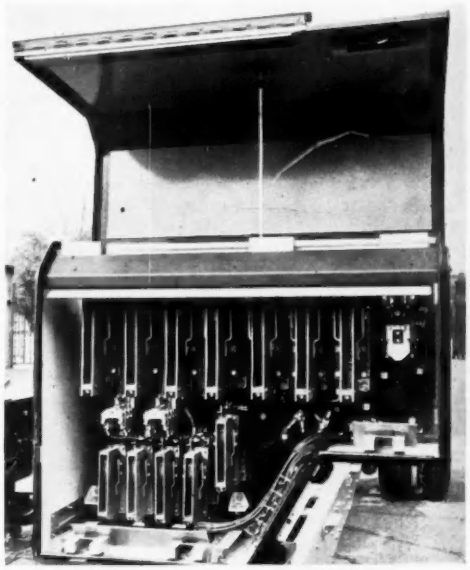

Fig. 4.—New design of all-metal contactor equipment case.

The moving contact arms are operated by means of quadrants attached to the operating levers. In addition to the various control sections for acceleration and speed control, together with rheostatic braking control, the main reverse drum, with positions for battery manœuvring, is embodied in the controller. The compact arrangement thus obtained simplifies interlocking, as, for example, between the control sections and the reverse drum, which are interlocked to ensure that the power control section cannot be moved unless the reverse drum is in its correct position ; nor can the reverse drum be moved unless both control sections are in the " off " position.

The changeover switch for battery manœuvring changes the two sections of the battery from parallel to series, and the extra positions on the reverse drum provide the appropriate connections for motoring from the battery. After setting up for battery manœuvring, movement of the bus is controlled by a foot switch.

The trolleybus chassis were built by British United Traction Ltd. and the bodies by Park Royal Vehicles Ltd. The chassis, 30 ft. long by 8 ft. wide, has a wheelbase of 18 ft. 7 in., giving a turning circle of 66 ft. The traction motor is mounted in a position behind the statutory 10 in. ground clearance limit and is attached to the frame by resilient mountings. From the motor, the drive is taken to the rear axle by a propellor shaft of open tubular seamless construction fitted with Hardy-Spicer needle roller couplings.

Each bus seats 70 passengers in lower and upper saloons. The upholstery has been chosen to blend with an interior colour scheme of dark green enamel to the waist, light green to cant level, and off-white enamel ceilings. Lighting is by means of semi-sunk open reflector fittings. Air for ventilation is ducted to a baffle on the bulkhead arch panel in the lower saloon, and to another baffle fitted above the upper saloon front windows. Extractor vents are mounted on the upper saloon roof and on the cab, and sliding windows

Fig. 5.—The master controller.

are provided in both saloons, four on the lower and six on the upper deck.

The latest vehicles have been put into service on new routes, some of them replacing trams. They are finished externally in the Glasgow fleet colour scheme of orange, green and cream, with the Glasgow coat of arms on the body sides.

Conveyor System for Railway Tunnelling Operations

By B. S. PELTON, B.Sc.(Eng.), A.M.I.E.E., and R. A. STEVENS,
Erith Engineering Works.

Fig. 1.—New tunnel portal (left) at Potters Bar.

ABOUT 12 miles north of the London terminus at King's Cross, the main line of the Eastern Region, British Railways, narrows from four tracks to two where it tunnels through the hills near Potters Bar, in Hertfordshire. This double-track section extends for 2½ miles between Potters Bar and Greenwood, and on it are situated the Potters Bar, Hadley South and Hadley North tunnels, with lengths of 1,208 yd., 383 yd. and 232 yd. respectively. The "bottleneck" through the tunnels now carries some 350 trains daily and has exercised an increasingly restrictive effect on the working of the main line, which forms part of the East Coast route to Scotland and also carries heavy goods and passenger traffic to and from the Midlands and the North.

The first stage of a scheme for increasing the capacity of the line by various measures, including the provision of four tracks or more over the whole distance from King's Cross to the Welwyn Viaduct (21 miles), was put in hand in 1953, and completed in 1955 with the opening of a new station and other installations at Potters Bar. Work has now moved on to the Potters Bar-Greenwood section, where three new double-track tunnels are being constructed parallel with the existing ones in order to accommodate two additional running lines. The main line from King's Cross to York is to be electrified on the 25 kV single-phase a.c. system, and the tunnels are therefore being constructed so as to allow the clearances required for the catenaries and contact wires. Spoil is removed during tunnelling by a conveyor system designed and supplied by the Fraser & Chalmers Engineering Works of the G.E.C. to meet the requirements of the civil engineering contractor, Charles Brand & Son Ltd.

The hills are composed of a hard clay and the excavation is being carried out by means of a cutting shield, 31 ft. in diameter, with transverse members

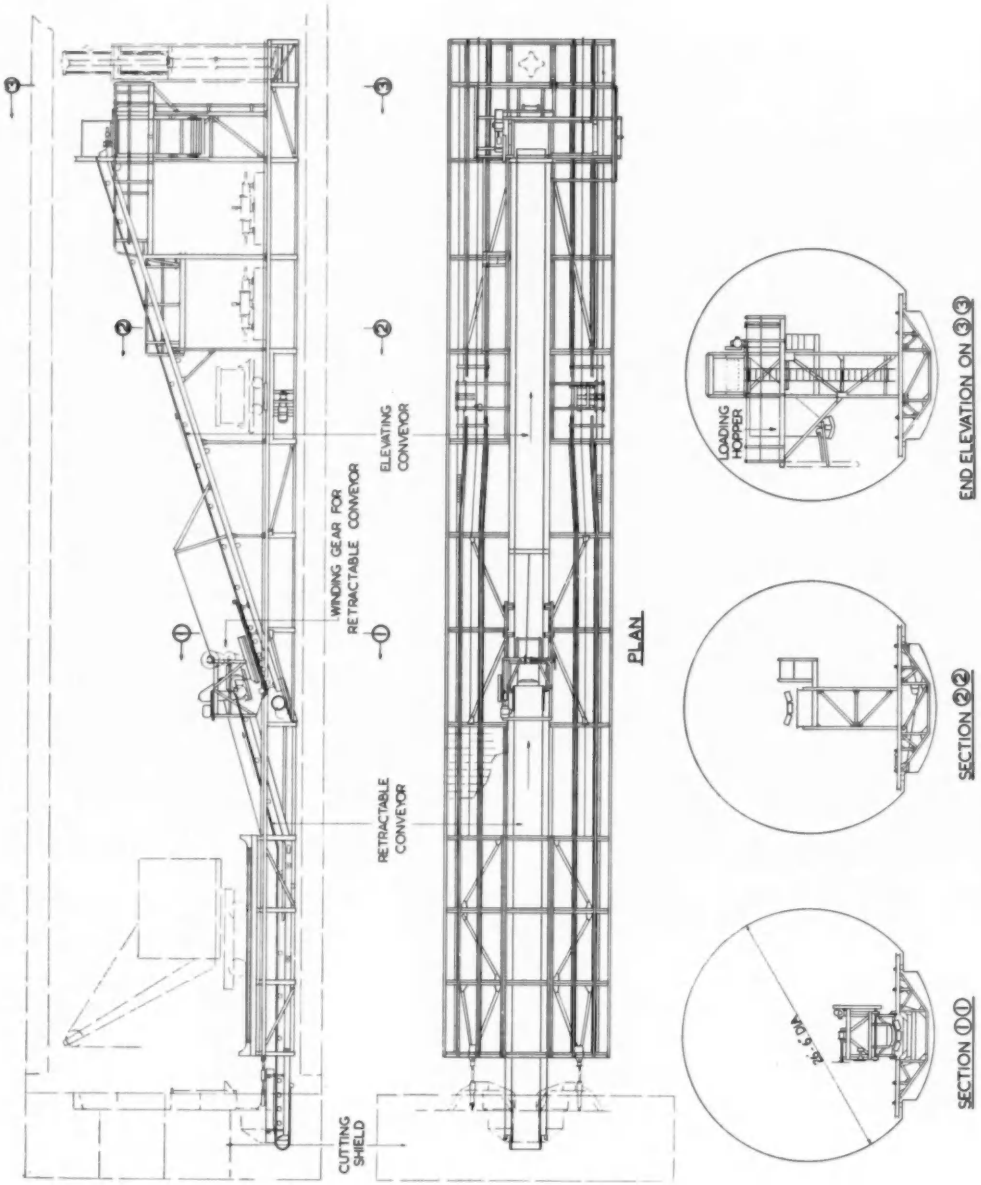

Fig. 2.—General arrangement of the conveyor assembly.

dividing it into twelve compartments. Twenty-five hydraulic rams spaced round the rim move the shield forward as required. Miners working in the compartments excavate the clay with pneumatic spades and shovel the spoil by hand into a wide chute. It drops down to the conveyor system and is elevated to a small hopper, from which the tipping skips of spoil trains are loaded. Thus, the only point at which hand-shovelling is employed is at the cutting face. Thereafter the handling is mechanical.

The equipment (fig. 2) is carried on a steel framework, 116 ft. long, 17 ft. wide, and 23 ft. 6 in. high. Mounted on it are two 36 in. conveyor belts, the first of which is retractable in order to allow the invert block to be inserted. A platform and track for a 3-ton travelling crane are situated over the retractable conveyor. Rail tracks of 24 in. gauge are laid down the whole length of both sides of the framework, and an electrically-operated traverser is provided under the second (elevating) conveyor for moving the wagons from one side to the other. The spoil-loading hopper is at the discharge end of the elevating conveyor.

An hydraulic accumulator and pumps for operating the rams are mounted at the rear of the framework, which also carries all the necessary electric motors and switchgear. Skids underneath the framework rest on greased concrete ledges, which are integral with the invert blocks. The whole assembly, part of which is seen in action in fig. 3, is linked to the cutting shield by two screw couplings and advances with it.

A single-line rail track of 2 ft. gauge runs into the tunnel. There is a turn-out near the cutting face and from that point the lines run down both sides of the tunnel and are connected to the tracks on the conveyor assembly by means of telescopic rails. The tracks are extended as required by laying additional half-length or full-length rails.

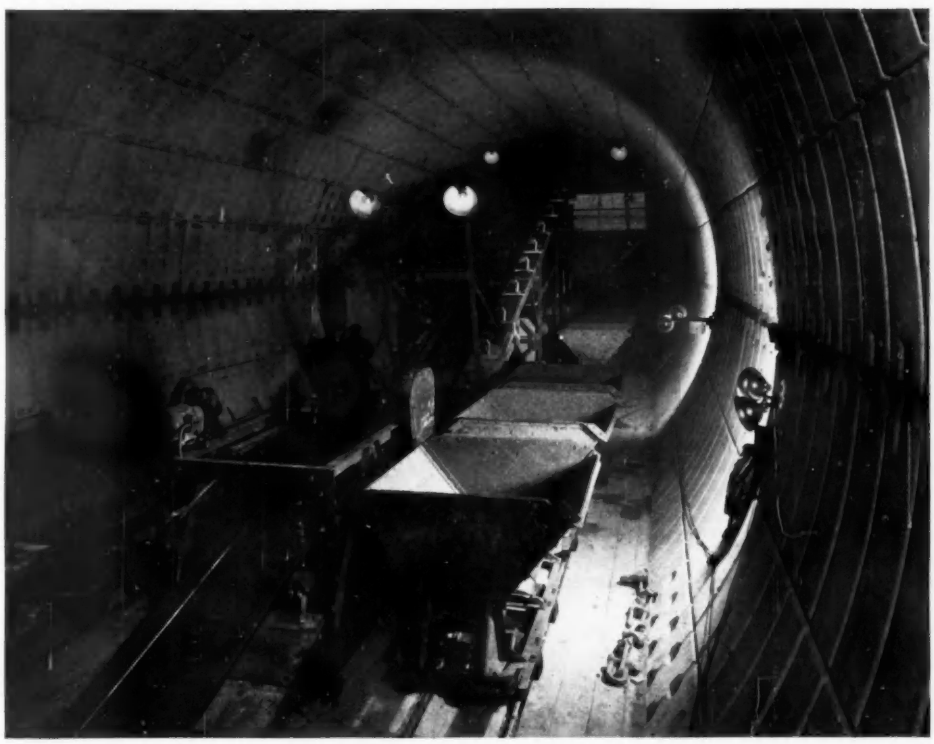

Fig. 3.—Conveyor installation in the tunnel.

The shield is in continuous operation except at week-ends, the work being carried out by three shifts per 24 hours. The clay, as it is excavated, is shovelled into the chute and drops on to the lower (retractable) conveyor. This belt delivers it to the second conveyor belt, which elevates it to the hopper at the top of the structure, situated directly over the track on the left-hand side. The spoil is loaded from the hopper into the skips through a power-operated gate.

Diesel locomotives are used to run the empty skip

trains into the tunnel and on to the track on the right-hand side of the conveyors. From there the skips are pushed by hand, one at a time, on to the traverser, which transfers them under the elevating conveyor to the opposite side ready to be loaded with spoil. The skips are run in turn under the hopper, and, as each is filled, it is pushed away down the track, which is on a slight downgrade, to where the remainder are waiting. When the whole train is full, it is pulled out to the disposal area, where the spoil is tipped out. The train is then run back into the tunnel and the operation is repeated.

Three times a shift a train-load of precast lining blocks is taken into the tunnel, each containing the blocks necessary to form a complete ring of the lining. These are specially made by Charles Brand & Son Ltd. in a factory near at hand. When the face has been advanced a distance of 18 in., far enough to take another ring of lining blocks, the shield is forced forward up to the face by means of the hydraulic rams pushing against the last ring of lining blocks. The conveyor belts are stopped, the rams are reversed into their cylinders and the retractable conveyor is drawn back over the elevating conveyor by means of a hand-winch. This leaves a clear space for the liners. The crane picks up the invert block, which is the full width of the conveyor structure, and drops it into place. The retractable conveyor is then drawn forward into place and loading is resumed with the minimum of delay.

The remaining liners, which are considerably smaller in size, are lifted by the crane on to an hydraulic mechanism which is designed to raise them into place and lock them in position without interfering with the removal of the spoil (fig. 4).

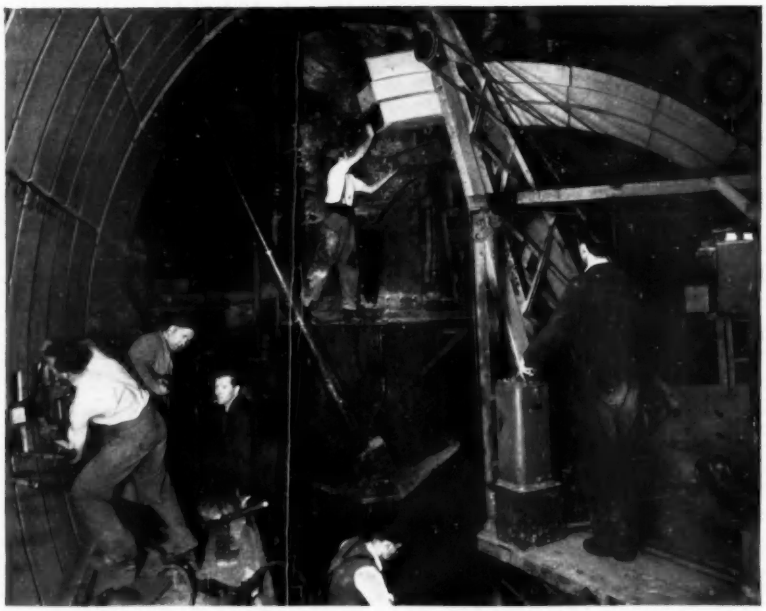

Fig. 4.—Working face, showing cutting shield and hydraulic mechanism for putting lining blocks into place.

The advantage of the conveyor system is that it ensures the continuous removal of the spoil from the working face except during the comparatively short time necessary to drop the invert blocks into place. The expense of the plant is justified by the speed and continuity of the operation. At first glance the 36 in. conveyor belts provided would appear to be unnecessarily large for the removal of no more than 15 cu. yd. of spoil per hour. With the cutting-shield method of excavation, however, the discharge of clay from the face is liable to be irregular, with occasional high peak loads. The wide belts provided clear it with minimum spillage and consequently without the expenditure of time and labour in clearing out the bottom of the excavation.

Electronic Indicating and Control Systems

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Telephone Works, Coventry.

With electro-mechanical control and supervisory methods, there are limits to the number of controls which can be transmitted or the amount of information received in a given time. The electronic systems described in this article use cold cathode triodes as the basis of equipments which transmit information in a fixed sequence, continuously repeated. Thus, if several changes occur together in the condition of the apparatus to be indicated, or a number of control switches is operated, there is no waiting for one piece of information to be transmitted before transmission of the next can begin.

IN many types of undertaking with installations dispersed over a large area, it is necessary to provide a means by which indications can be passed from the outstations to a main station, and controls can be transmitted from this main station to the outstations. For example, in a hydro-electric power generating and distribution system the information to be transmitted could be the power generated and transferred, the position of circuit breakers and transformer tap-changing gear, water level, and the condition of the various alarm circuits. In such a system it might be necessary to alter gates and valves to control the flow of water, and circuit breakers and transformer tappings to control the flow of electrical energy. On a railway system the requirement might be to indicate at a control room the positions of all trains on the line, and the condition of all signalling apparatus. In this case the mechanisms to be controlled would be the signalling apparatus itself. In many other networks similar problems arise where centralised control of the network enables considerable economic advantages to be obtained.

There is, therefore, a requirement for equipment which provides remote indication of a number of quantities and remote control of mechanisms. This is already available in a number of forms, but investigation showed that further facilities could usefully be added. The Electronic Digital Indicating and Control Transmission (EDICT) equipment described in this article has been specially designed to permit continuous control of a widespread system. A similar equipment, the Electronic Digital Information Transmission (EDIT) equipment, can be used when only back indication is required and no control facilities are needed.

By means of either equipment it is practicable to maintain a mimic diagram of any system completely up to date. Any change in any of the quantities measured is shown on the diagram in under three or four seconds. Of even more importance, it does not matter how many such changes occur at one time. There is no delay while one change is being transmitted before another change can transmit its indication. The control engineer is therefore presented with a picture of the complete system and knows that this picture is of the system as it is at the moment and not of what it was some minutes ago. If the EDICT equipment is used he can then carry out the necessary operations knowing that the movement of a control switch is followed immediately by that of the mechanism which he wishes to control, and that if he moves ten or twenty such switches at one time the corresponding mechanisms will alter their position within three or four seconds and that there will be no waiting time for one mechanism to complete its operation before the next control is transmitted.

METHODS OF TRANSMITTING INFORMATION.

Information can be transmitted from one point to another either in parallel form or in serial form. When information is transmitted in parallel form it is necessary to have between the two points a number of communication channels which increases in proportion to the amount of information to be transmitted. Such a situation occurs when the positions of all the circuit breakers in a substation are indicated on a local mimic diagram. From each circuit breaker one or more wires run to the diagram and cause the appropriate lamp to be illuminated. Obviously such a method of passing the information would be completely impracticable if it were desired to indicate the positions of the circuit breakers at a point situated twenty miles away, since the cable required to carry a large number of wires over such a distance would be extremely expensive.

To reduce the size of the cable the information can be passed in serial form. One method of doing

this would be to supply a telephone link between the two points and to have operators at each end, one reading out continuously the positions of the various circuit breakers and the readings of the meters, and the other altering the mimic diagram appropriately. Relay equipment is well known which uses a modification of this principle, information being transmitted only when a change occurs in one of the quantities, circuit breaker positions or meter readings, to be remotely indicated. In such equipment the time taken to send indications if a number of changes occurs simultaneously may be unacceptable, particularly if a meter reading is varying continuously.

This difficulty does not exist if the speed at which the system can pass information is sufficiently high. It is then possible to transmit the information on all quantities in a fixed sequence which is repeated continuously. This has the additional advantage that, after any interruption to the transmission, no special procedure is necessary to bring the mimic diagram to its correct state. An equipment to carry out these functions could be manufactured using relays and uniselectors, but as will be seen, the speed of operation and the life of such an equipment would not be satisfactory. It is, however, useful to consider how such an equipment would operate since the EDIT and EDICT equipments use similar principles.

AN ELECTRO-MECHANICAL VERSION OF 'EDIT'.

An equipment using relays and uniselectors is shown in diagrammatic form in fig. 1. The essential portion of the equipment is some form of sequence switch or distributor. This could consist of a motor driving a wiper which makes contact in succession with various points, or it could consist of a uniselector. If a motor were used it would be necessary to ensure that the motors at the main station and at the substation were running at exactly the same speed. A more convenient method would be to use uniselectors, since the uniselectors at the main station and at the substation can be driven by the same pulses. If the uniselector at the main station has a greater number of positions than the one at the substation, it is possible to provide a circuit which verifies that the two uniselectors are moving in the correct relative phase. This is done by using the uniselector at the main station to break the transmission of pulses to the substation while it is on the extra positions. At the substation a slow-release relay detects this gap in the locking pulses and examines the position of the uniselector at that time. If the uniselector is in the correct position this fact can be recorded, if not it can be reset to the correct position.

Contacts of another bank of the uniselector at the substation are connected to contacts which give the information to be transmitted, and corresponding contacts of a bank of the uniselector at the main station are connected to indicating lamps. The wipers of these two banks are connected by a transmission channel which carries the information in serial form.

If the information to be transmitted is already in "yes-no" form it can be fed to the contacts of the uniselector bank directly. If, however, it is in a continuously variable form, such as a meter reading, it must be coded before it can be transmitted. The result of such coding must be to convert the meter reading to a series of contacts which are either open or closed. These two conditions can be represented by the digits 0 and 1, which are the two digits of the binary scale. They are therefore referred to as binary digits or "bits". Using seven bits, a meter reading can be coded to a nominal accuracy of 1 part in 128, since each bit reduces the number of possibilities by a factor of two. Where less accuracy is needed, the number of bits can be reduced, four bits giving

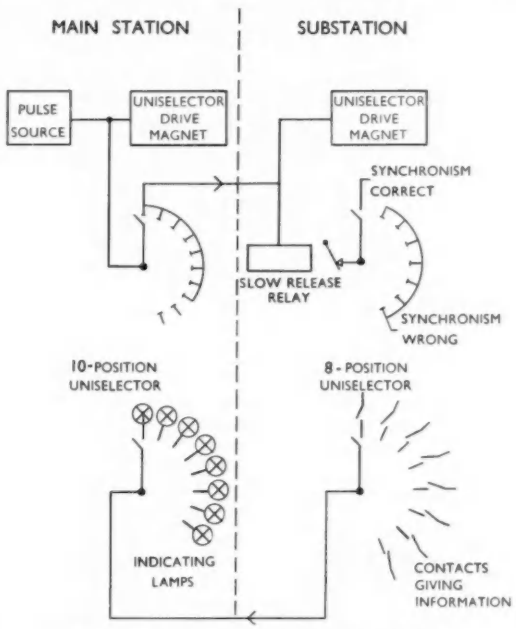

Fig. 1.—Electro-mechanical version of EDIT.

an accuracy of 1 part in 16. This coding into binary digital form can be carried out in many different ways, the particular method for any case being chosen according to the requirements.

A disadvantage of the system as outlined above is in the method of presentation. It is obviously a requirement that the indications on the mimic diagram should be presented not intermittently but continuously. This means that information, when it has been received, must be stored in some circuit and that the indicator should be fed from the store. Such a store can be obtained from relays which each have a holding contact and winding. If the energising and holding circuits are so arranged that one or other but not both of the circuits are completed at any time, the relay will remain operated if the appropriate bit

is 1, but if the bit becomes 0 the energising voltage will never be present, and the relay will release and remain released. Since the information from one meter is contained in a number of bits it is advisable to alter the position of all relays corresponding to one meter simultaneously. Otherwise the indicated reading could swing violently while the bits were being transferred. Received information is therefore stored temporarily in one of two stores, each store holding a group of bits. Once all the information has been written into a temporary store it can be transferred as a group to the permanent store and the temporary store erased. Meanwhile the incoming information is being written into the other store.

The speed of operation and the life of such an equipment using relays and uniselectors would not be very satisfactory. A typical substation might require four meter readings to be transmitted to an accuracy of 1 part in 128, two water levels to an accuracy of 1 inch in 16 ft., eight circuit breakers, and a number of miscellaneous switches and alarms. The total amount of information would then be approximately 80 bits. If a signalling speed of ten pulses per second were used, which is a reasonable maximum for electro-mechanical apparatus, the cycle time, ignoring any time allowed for the synchronising gap, would be 8 seconds. If the life of the uniselector is taken as 100 million operations, the life of the equipment would be under four months. It is therefore apparent that such an equipment is not practicable if it is based on the normal type of electro-mechanical device.

A satisfactory design of equipment requires a device with a very much longer life, and preferably also a faster speed of operation which would enable more information to be passed in the same time. This latter provision would also enable the equipment to conform more closely with the capabilities of normal communication channels since the narrowest channel available is a voice-frequency telegraph channel, capable of operating at fifty or sixty bits per second, and therefore underemployed by a factor of five or six when carrying ten pulses per second.

THE COLD CATHODE TRIODE.

A very satisfactory device to use as the basis of such an equipment is the cold cathode triode. This type of tube contains only three electrodes—the anode, the cathode and the trigger. Since it is designed for operation with the cathode cold, no heater is required and the tube therefore consumes no power except when it is actually in use. In addition, the reliability and life of cold cathode tubes are considerably greater than those of hard valves.

The cold cathode tube contains a small amount of gas, a mixture of neon and argon, at a low pressure. If a positive voltage is applied to the trigger electrode, a glow discharge takes place between the trigger and the cathode. This glow initiates a glow discharge between the anode and the cathode which continues until the h.t. supply to the tube is considerably reduced. Extensive development work has been carried out to produce a tube with a very long expectation of life, and to evolve circuits which do not make critical demands on the tube. This work has resulted in the G.E.C. cold cathode triode, CCT6, and in the voltage-transfer technique of interconnecting the tubes. The voltage-transfer technique works by switching the output of one tube directly to the input of another. This is possible because the CCT6, unlike most cold cathode tubes, produces at its cathode a useful output greater than the input required to switch on a tube.

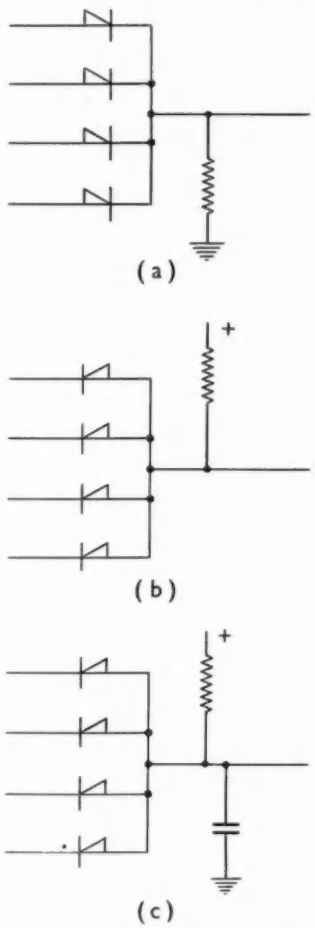

Fig. 2.—Voltage transfer circuit elements.
(a) "OR" gate.
(b) "AND" gate.
(c) Slow-operate element.

CCT6 CIRCUITS.

In the voltage-transfer technique the networks between the tubes consist of OR and AND gates. An OR gate is a gate which gives an output when a

signal is applied to any one of its input terminals. It consists of a number of rectifiers connected from the input terminals of the gate to the output terminal with such a polarity that a signal applied to an input terminal makes the corresponding rectifier conduct, as shown in fig. 2a. The rectifier therefore appears as a low resistance and the majority of the input signal appears across a resistor connected from the output terminal to earth.

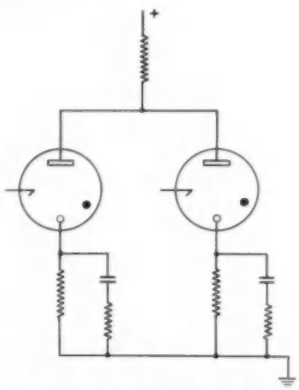

Fig. 3.—Mutually-extinguishing tubes.

An AND gate is a gate which gives an output only when signals are applied to all its input terminals. It consists of a number of rectifiers connected from the input terminals of the gate to the output terminal with such a polarity that a signal applied to an input terminal stops the corresponding rectifier from conducting as shown in fig. 2b. The output terminal is connected to the h.t. supply by a resistor. An output is therefore obtained from the gate only if none of the rectifiers is acting as a short circuit from the output to earth, i.e. none of the inputs is absent.

A slow-operate element, in which there is a delay between the occurrence of all the inputs and the output, can be obtained by a modification of an AND gate which involves the addition of a capacitor from the output of the AND gate to earth as shown in fig. 2c. The output voltage then rises towards the h.t. voltage while all inputs are present at a rate depending on the values of the resistor and the capacitor. It is possible to obtain slow-operate times between 25 milliseconds and 2 seconds approximately.

The outputs from these gating circuits can be used to trigger tubes. A chain of tubes can be made mutually extinguishing by providing them with a common anode resistor and ensuring that the cathode load of each tube contains a capacitor. A practical circuit is shown in fig. 3. When a tube is struck it draws initially a comparatively large current which results in a voltage drop across the anode resistor. Any tube in the same chain which was previously conducting then has a reduced anode voltage but its cathode voltage is maintained by the capacitor in its cathode circuit. There is therefore insufficient voltage across the tube to maintain the glow discharge and the tube is extinguished.

A counter is shown in fig. 4. It is made by taking a chain consisting of an even number of mutually-extinguishing tubes. Each tube is triggered from an AND gate to which there are two inputs, one from the preceding tube in the chain and one from a " stepping " input. If there are two such " stepping " inputs and they are connected to the triggering circuits of alternate tubes, a voltage on one of the inputs will transfer the glow from an odd tube to the following even tube. A voltage on the other input will transfer the glow from an even tube to the following odd tube. So, if pulses are applied to the two " stepping " inputs alternately, the glow will be transferred in succession from the first tube in the chain to the last tube. The chain can be converted into a ring by connecting a similar AND gate as the triggering circuit of the first tube, with its inputs from the last tube and from the appropriate " stepping " input. Then pulses applied to the two " stepping " inputs alternately will cause the ring to rotate continuously.

Outputs can be taken from two of the tubes in the ring and used as the " stepping " inputs to another ring, which will then rotate at a slower speed, taking two steps for one rotation of the first ring. The number of rings can be increased as required in the same way as the number of wheels in the mileometer of a car, and by feeding from an appropriate point in each of the rings, an output can be obtained from an AND gate at any point in the cycle. These counter rings can therefore be used as a distributor instead of the uniselector which was used in the electro-mechanical example (fig. 1). Since there are no mechanical moving parts, the speed of operation can be increased and there will be no mechanical

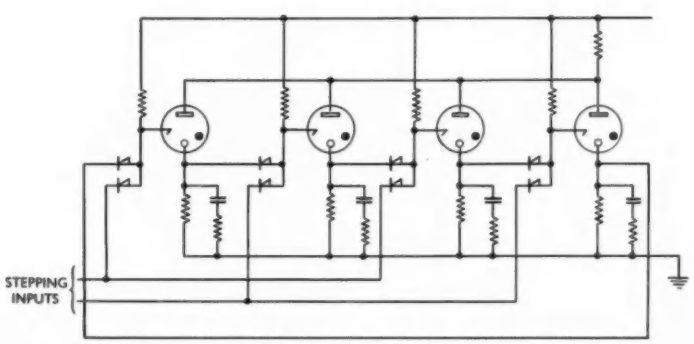

Fig. 4.—Basic circuit of counter.

wear. A suitable speed to use is that given by the mains supply, i.e. 50 or 60 steps per second. In the remainder of the description a speed of 50 steps per second will be assumed.

THE 'EDIT' EQUIPMENT.

It is now possible to consider how the EDIT equipment is made up. Fig. 5 is a block diagram of the equipment for a system with one substation only from which an amount of information represented by 160 bits is transmitted to a main station. Two telegraph channels are required for linking the two stations. One of these channels, called the locking channel, feeds the locking pulses from the main station to the substation and ensures that the distributors at the two stations are running in synchronism. The other telegraph channel, called the backward information channel, carries the backward information from the substation to the main station. Although two channels are required they can be obtained on a single pair of wires by transmitting the pulses as bursts of oscillations at a frequency in the range which can be carried by a normal telephone circuit and by using different frequencies for the two directions of transmission. The locking channel carries a train of 88 pulses, each approximately 20 milliseconds long, separated by gaps also of 20 milliseconds. This is followed by the synchronising gap which is approximately 320 milliseconds long. The complete cycle time is therefore 3·84 seconds. Eighty of the pulses and eighty of the gaps define the intervals of time to which the bits of information are allocated. The remaining pulses are required to compensate for time delays in the telegraph channels. The backward information channel carries the information in the form of 160 pulses each approximately 20 milliseconds long with no gap between the pulses. Any pulse can be either present or absent, depending on the information to be transmitted.

The equipment at the main station consists of three basic portions—the distributor, the locking transmitter and the backward information receiver. The distributor is the basic circuit which defines the time intervals throughout the cycle of operation. It consists of four rings of counters, known as the M, P, Q and G rings. The first ring, the M ring, is driven by pulses obtained from a transformer fed by the mains supply. The other rings are each fed by two of the tubes in the preceding ring. The locking transmitter contains those tubes which control the pulses fed from the main station to the substation to control the distributor at the latter.

Two chains of tubes are concerned with obtaining the required pulse pattern—the locking transmitter control chain and the locking transmitter tubes themselves. The control chain is used to note the position in the cycle of the distributor at the main station. One tube is struck when the locking pulses should be transmitted, the other when the synchronising gap is required. These tubes feed the locking transmitter tubes which, in their turn, feed the telegraph transmitter.

The backward information receiver consists of a number of gates, controlled by the distributor, which feed the information received by the telegraph receiver to the appropriate position in one of two temporary stores, each of which has capacity for 8 bits. While the information is being written into one store, the information in the other store is transferred by means of a relay operated by the distributor to the appropriate permanent relay store. The temporary store is then

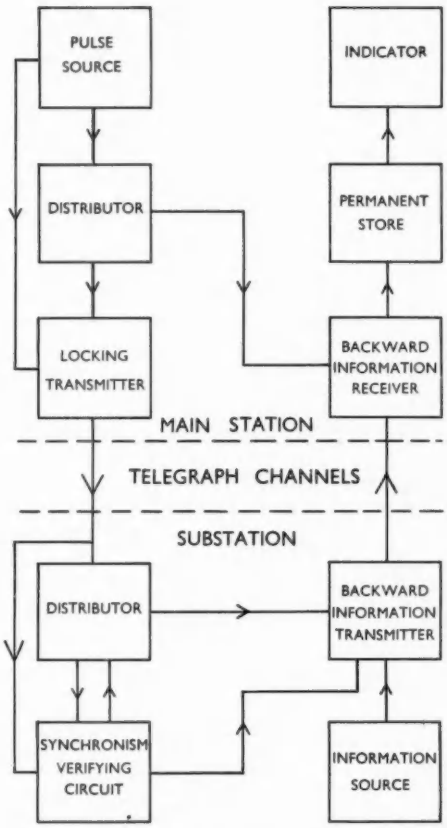

Fig. 5.—Block diagram of EDIT.

erased and is therefore ready to accept the next information. The relay stores can feed information to any form of indicator on the mimic diagram; normally the presentation will be either by lights or by a meter. Other circuits are incorporated to provide the necessary voltages to start the equipment when it is switched on and to detect any failure. Test keys are fitted to enable the circuits to be tested at slow speed.

The equipment at the substation also consists of three basic portions—the distributor, the synchronism verifying circuit and the backward information transmitter. The distributor consists of three rings

of counters known as the P, Q and G rings. The P ring is driven by the locking pulses received from the main station. The other rings are each fed by two of the tubes in the preceding ring. Each of the rings has an additional tube which is struck when it is necessary to reset the distributor. This resetting is carried out, when necessary, by the synchronism verifying circuit, which examines the point in the cycle which has been reached by the distributor each time the synchronising gap is received. If the distributor is at the correct point a " synchronism verified " pulse is transmitted at the appropriate point in the cycle ; if not, it is reset.

The backward information transmitter contains the gates by which the distributor scans the information to be transmitted. These gates feed the neces-

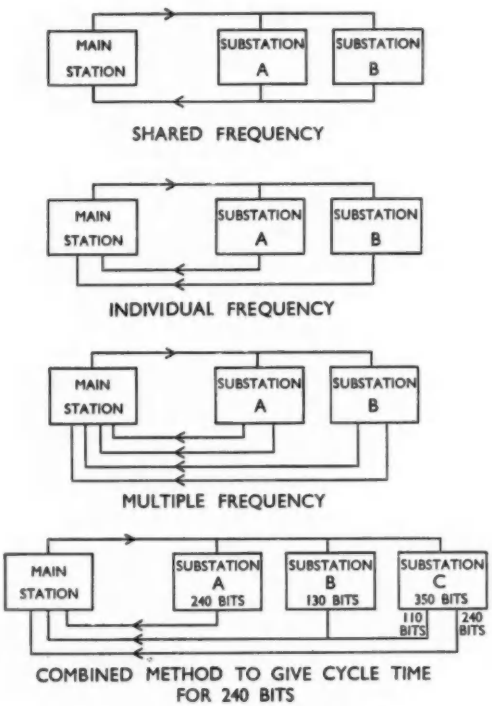

Fig. 6.—Methods of multi-station working.

sary signals to the telegraph transmitter so that pulses are transmitted at the correct times. It also contains the circuits which are used as the fine adjustment when compensating for time delays in the telegraph channels. Other circuits are incorporated in the equipment at the substation to provide the necessary voltages to start the equipment when it is switched on and to detect any failure. Test keys are fitted to enable the circuits to be tested at slow speed.

ADJUSTMENTS FOR SIGNALLING DELAY.

In order to obtain allocation to the correct groups of the information contained in the pulse train, it is necessary to ensure that the distributors at the main station and the substation are driven not only at the same frequency but in the correct relative phase. The same frequency is ensured by the transmission of the locking pulses ; a constant relative phasing is ensured by the synchronising gap. To ensure that this phasing is the correct one, an adjustment is necessary at the substation to compensate for the signalling delay in the telegraph channels. Owing to the time delay in the locking channel, the substation distributor will step away from the position at which the synchronising gap was received some time after the main station distributor steps away from the end of the synchronising gap. If a pulse is transmitted by the substation at this time there will be a delay before it is received at the main station.

As a result of the addition of these two delays the main station distributor will be a number of steps away from the end of the synchronising gap. It is therefore apparent that the synchronising gap should occur at a later point in the cycle at the substation than it does at the main station. To allow this to take place a number of additional steps in the cycle are introduced and a control is provided at the substation which enables the point in the cycle at which the synchronising gap should occur to be selected. Since the sum of these delays is not necessarily equivalent to a whole number of steps, a fine control is provided at the substation which can introduce a variable delay, adjustable to make the total delay equivalent to a whole number of steps.

MULTI-STATION WORKING.

It will be apparent from the previous description that a number of substations can operate with one main station. The complete cycle time is divided into the necessary number of portions, one portion being allocated to each substation. The transmissions from the substations follow each other in sequence and are received by a common receiver at the main station. If the amount of information to be transmitted from each substation is very great, a shared frequency could result in a cycle time which might be too long for the particular application. Each substation can then be allocated an individual frequency for the backward information telegraph channel. The distributor and the locking transmitter at the main station are common to all substations but separate receivers are required.

If the amount of information from each substation is greater still, more than one frequency can be allocated to each substation. This necessitates transmitters at a substation for each frequency used by that substation, and receivers at the main station for all the frequencies used in the system. If different amounts of information are originated at each substation, any combination of the shared frequency, individual frequency, and multiple frequency methods can be used, the particular combination used being dependent

on the amount of information originated at each substation and the cycle time required. The various methods are shown in diagrammatic form in fig. 6.

THE 'EDICT' EQUIPMENT.

In the EDICT equipment additional facilities are available which enable information to be passed from the main station to the substations. This information

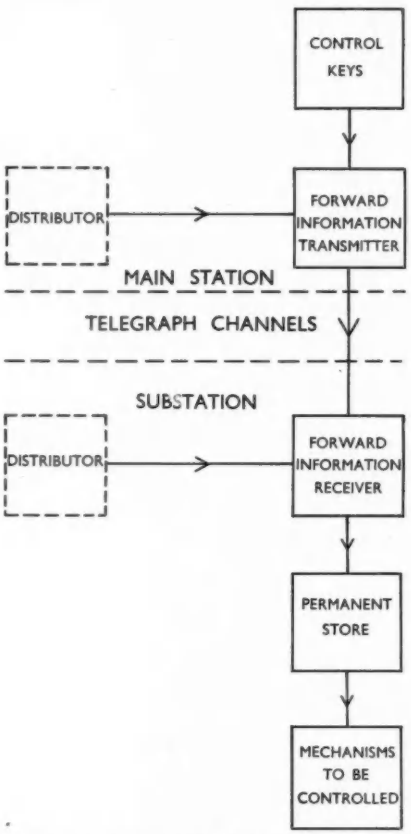

Fig. 7.—Block diagram of additional equipment in EDICT.

will normally be used to control apparatus at the substations. To carry the information an additional telegraph channel known as the forward information channel is required. This carries the information in a similar manner to the backward information channel. There is a minor difference in that 20-millisecond pulses, which are either present or absent to give the information, are separated by 20-millisecond gaps. The rate of transfer of information is therefore reduced from 50 bits per second which is available on the backward information channel to 25 bits per second. This speed is perfectly satisfactory since the capacity for control information required on a system is normally considerably less than that for back indication.

The additional equipment required at the main station and at a substation for the control facility is shown in fig. 7. At the main station the existing distributor is used to switch the gates which sequentially scan the input keys. These gates trigger the forward information transmitter tubes, which in their turn control the telegraph transmitter. At the substation the information is received on a telegraph

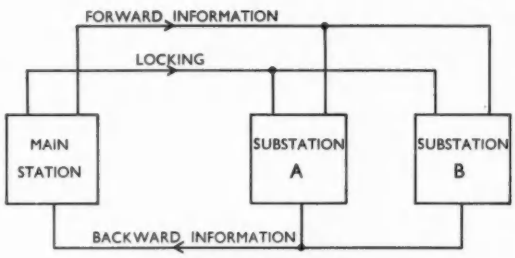

Fig. 8.—Basic EDICT system.

receiver and, after the necessary adjustment to allow for the relative delays in the locking and forward information telegraph channels, is fed to one of two temporary stores. Information is transferred from one of the temporary stores to the permanent relay store while other information is being written into the other temporary store.

The basic EDICT system is therefore as shown in fig. 8. If the amount of control information is increased, additional telegraph channels can be allocated to the transmission of forward information. This is analogous to the use of additional frequencies for the backward information transmission and the same possibilities of shared frequency, individual frequency, and multiple frequency working exist. Using the same basic units, a large number of different systems can be built up having different numbers of channels and cycle times.

Back-pressure Turbine at National Physical Laboratory

Fig. 1.—The 650 kW geared turbo-alternator.

DURING the past fifty years the National Physical Laboratory at Teddington has grown from virtually a single building to a built-up area of 65 acres. As this expansion took place, boiler houses were built to meet the heating requirements of each individual building, until eventually there were 19 such boiler houses, which, with their associated dumps of coal and coke, occupied a considerable area.

Some three years ago the Ministry of Works decided to undertake an integrated heating scheme, based on a new boiler house and power house to serve the whole establishment. It was found that appreciable economies could be realised by expanding the steam in a turbine before passing it to the heat exchangers from which the medium-pressure hot water required for the present heating systems is derived, and by making use of the output from an alternator coupled to the turbine.

For this scheme the G.E.C. supplied a 650 kW geared turbo-alternator to the requirements of the Ministry of Works. The set, illustrated in fig. 1, operates normally in parallel with the South Eastern Electricity Board's supply, and serves to flatten the peaks of the establishment's maximum demands on the supply system, which tend to coincide with the maximum heating demand. Fig. 2 shows the control board incorporating the alternator control and protection and the synchronising equipment for use when interconnecting the two supplies.

The alternator supply is also used for all auxiliaries in the new oil-fired boiler house (fig. 3), dispensing with the need for standby steam plant such as boiler feed pumps, and for essential loads in the establishment. Power for these purposes is taken from a house transformer connected on the alternator side of the oil circuit breaker, so that in the event of a mains failure throwing a sudden exceptional load on the set, the tripping of the circuit breaker will not isolate the boiler house and essential services.

The new boiler and power house, which was designed by Mr. H. A. Snow, A.R.I.B.A., is equipped at present with four 13,500 lb./hr. Sinuflo Economic boilers raising steam at 225 lb./sq. in. and with approximately 150 deg. of superheat. The boilers are oil-fired, and the burners are controlled automatically by equipment which also provides automatic fuel/air ratio control.

The turbine, with inlet steam conditions of 210 lb./sq. in. at 540 deg. F., is designed for back-pressure operation, exhaust steam at 40 lb./sq. in. being desuperheated and delivered to the calorifiers for central heating purposes. To ensure that the heating requirements can be met under all conditions of electrical load, a by-pass line with a reducing valve and desuperheater is fitted so that additional steam for space heating can be supplied (via the reducing valve) should the back-pressure of the turbine fall by 1 lb./sq. in. below the normal value. Water from the calorifiers is circulated at 240 deg. F. by means of a new system of pressurised distributive mains from which the various buildings are fed. Certain areas still need to be supplied with steam, and provision is made to take the back-pressure steam direct to the distributive points serving these areas.

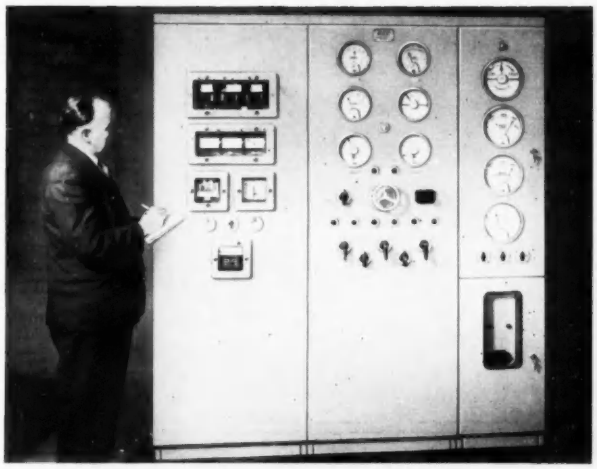

Fig. 2.—Alternator control and synchronising board.

When the set is synchronised with the grid the back-pressure is maintained at a constant value by a pressure regulator, the electrical output varying according to the demand for heating steam. It is also possible to run the turbine under speed-governing conditions when isolated from the grid, with the back-pressure correctly maintained by high-pressure steam supplied through the reducing valve.

The alternator, driven through 7,000/1,500 r.p.m. speed reducing gears manufactured by the David Brown Corporation Ltd., is rated at 650 kW maximum, 618 kW normal, 3 kV, 3-phase, 50 cycles.

Fig. 3.—The new boiler house and power house.

By the demolition of boiler houses and removal of fuel stores in connection with this scheme, valuable space has been made available. Advantage has been taken of this already to improve the layout of roads and add to the amenities of the site in various ways, while on a long-term view the planning of any further developments that may be required at the laboratories has been facilitated.

We are indebted to Mr. M. Woolfson, Senior Engineer, Ministry of Works, for facilities in connection with the preparation of this article.

Steelworks Power Station at Ravenscraig

By W. M. KERR, A.R.T.C., A.M.I.Mech.E.,
Turbine Division, Erith Engineering Works.

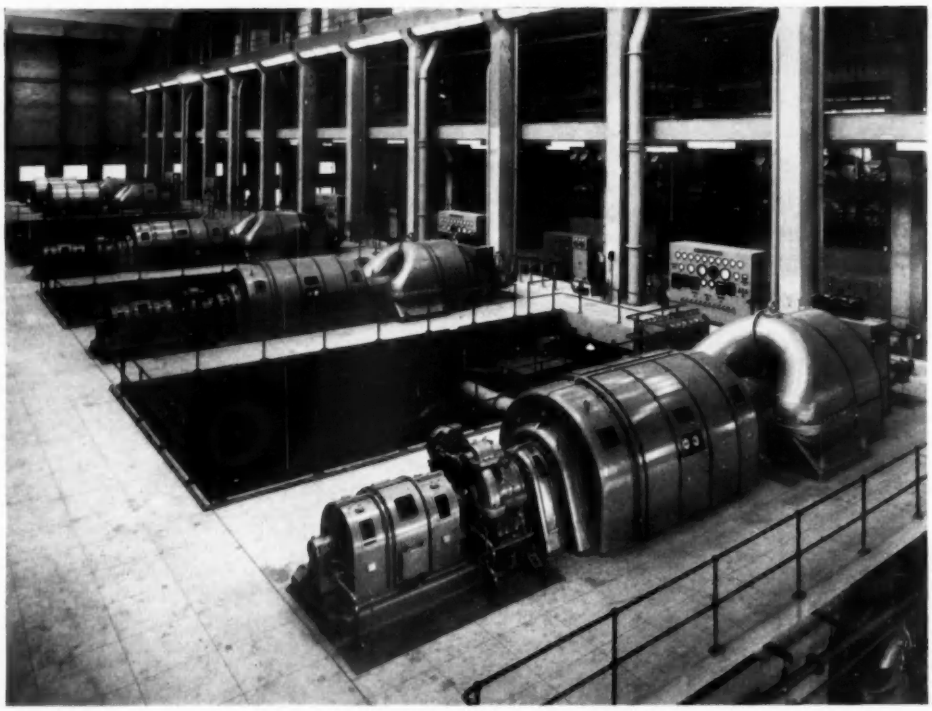

Fig. 1.—Turbo-alternators and blowers in the power house.

COLVILLES LTD., Scotland's major producer of iron and steel, has completed the first stage of a new integrated works at Ravenscraig, near Motherwell, Lanarkshire, about fifteen miles from Glasgow. This comprises a blast furnace, a battery of coke ovens, a by-products plant, a melting shop, and a power station ; future developments will entail two blast furnaces, two batteries of coke ovens, a rolling mill and extensions to the power station.

The G.E.C. acted as main contractor for the complete power station at Ravenscraig (fig. 1 and 2). The contract included buildings ; cooling towers ; four 125,000 lb./hr. boilers ; three 10 MW turbo-alternators ; two 90,000 c.f.m. turbine-driven blast furnace blowers ; two turbine-driven circulating water pumps ; feed heaters, condensers and ancillary plant ; together with switchgear and power and distribution transformers.

CIVIL ENGINEERING.

The power station building, which is of reinforced concrete brick-filled construction with shell roof, measures 280 ft. × 186 ft. and has an enclosed volume of over 3,650,000 cu. ft. To ensure a high level of natural lighting throughout the station, roof lights are embodied in each arch of the shell roof, and there are large windows in the front face of the building along the whole length of the wall above the switch-

gear annexe. The symmetry of the turbine and boiler house roof levels is also an important feature in achieving good natural lighting of the interior.

The interior lighting installation is of mixed fluorescent tubes and tungsten lamps with approximately 80 kW load, and the general illumination at the turbine house floor level is 15 ft.-candles.

The auxiliary transformer pens are recessed into the building on either side of the main entrance to provide a flush arrangement with the switchgear annexe. This annexe also serves to conceal the blower intakes, which draw air downwards from roof level, thus contributing substantially to the low noise level.

Two Davenport hyperbolic natural-draught, reinforced concrete, cooling towers with timber stacks serve to cool the condenser circulating water. These are 150 ft. dia., 227 ft. high, and the capacity of each is 1,200,000 gal. per hr. from 95 deg. F. to 72¼ deg. F. at 54 deg. F. wet bulb. They are designed to withstand a wind velocity of 90 m.p.h. The pond storage capacity of each tower is 1,106,300 gal. Circulating water is pumped from Colvilles' pumping station on the River Clyde.

The boilers use town water. A reinforced concrete storage tank of 100,000 gal. capacity is located adjacent to the cooling towers and the system is arranged for gravity feed to the raw water pumps.

BOILER PLANT.

Four Babcock & Wilcox bi-drum boilers (fig. 3) with water-cooled furnaces and self-supporting mild steel chimneys, 100 ft. high, are installed. These are for a maximum continuous rating of 125,000 lb./hr., 420 p.s.i.g., 820 deg. F., at the pendant type superheater outlet. The primary fuel is blast furnace gas, and provision is made for automatic control when using this fuel. The secondary fuel is oil, and two 600 ton oil storage tanks with two 35 ton service tanks give a large reserve to meet a temporary condition when blast furnace gas is not available. In future developments it may be necessary to convert the boilers to solid fuel firing, and arrangements are made to accommodate chain grate stokers if required. Due consideration has been given to this possible future requirement, the bunker side walls having been included in the building structure and the building arranged to accommodate conveyors for coke supply and ash disposal. Automatic detection of atmospheric carbon monoxide is provided at key points in the boiler space.

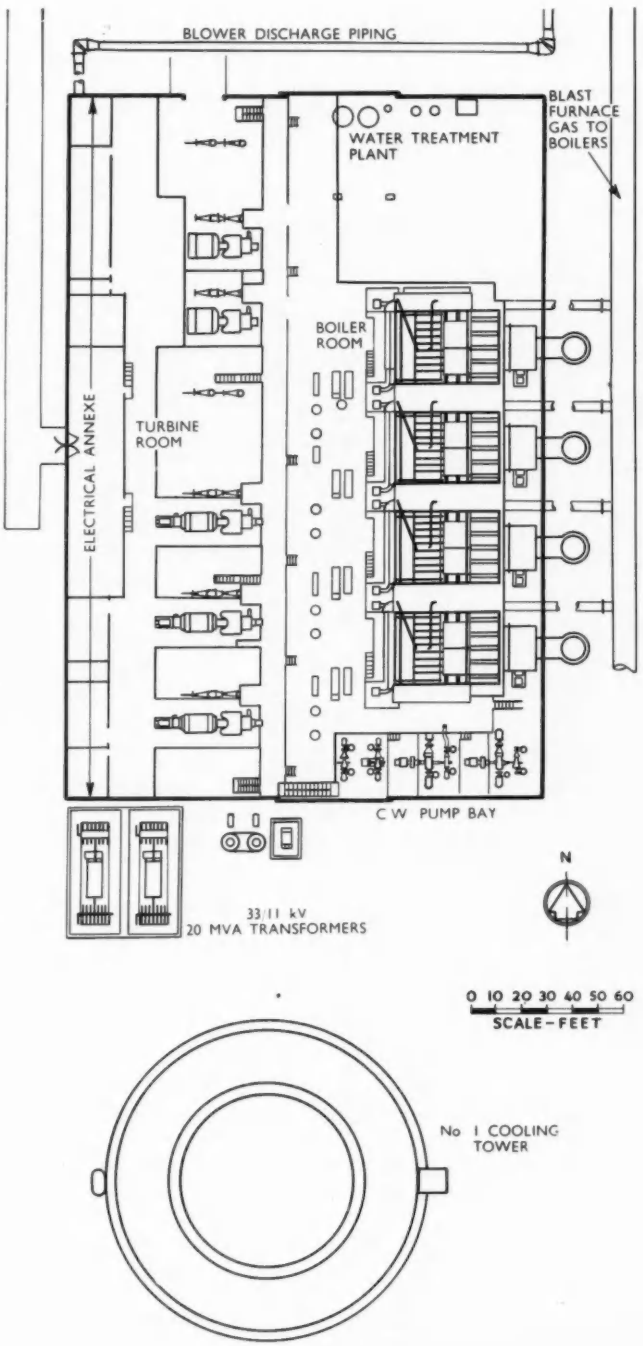

Fig. 2.—Plan of power station.

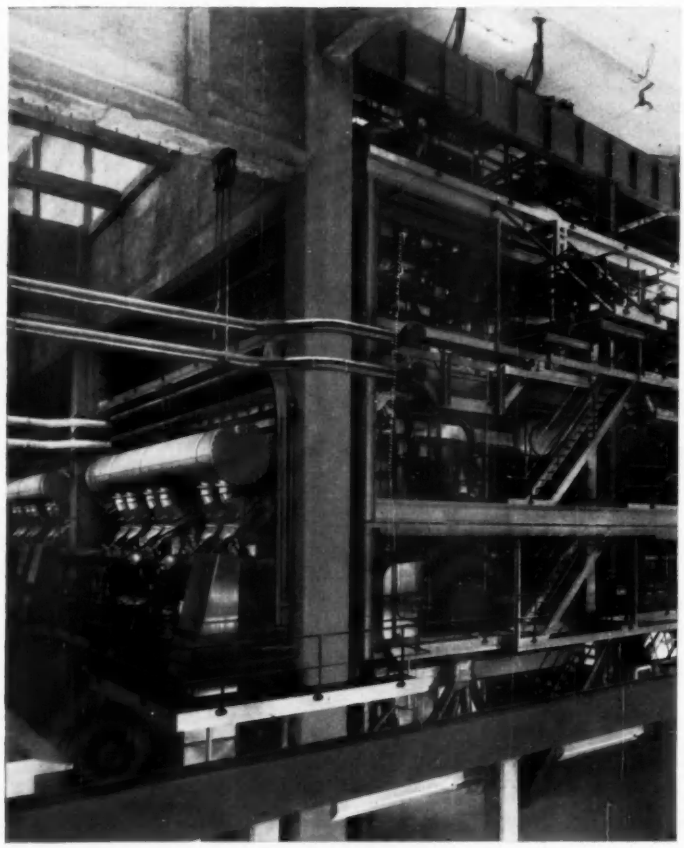

Fig. 3.—One of the four bi-drum boilers.

TURBO-ALTERNATORS AND BLOWERS.

The three 10 MW turbo-alternators are of the single-flow multi-stage impulse type, designed for steam conditions of 400 p.s.i.g., 800 deg. F., with 3-stage feed heating to 293 deg. F., vacuum 28.25 in. Hg. The alternators are of standard design with a continuous maximum rating of 11,765 kVA at 0.85 power factor, 3-phase, 50 c/s, 11,000 volts, 3,000 r.p.m. They are equipped with conventional bi-sectional closed circuit air coolers, which allow an output of 6,700 kW on one cooler section alone. The exciter and pilot exciter are totally enclosed and ventilated by air from the turbine house basement through viscous type air filters.

One of the turbines is arranged temporarily to operate on 100,000 lb./hr. of melting shop waste heat boiler steam at 245 p.s.i.g., 730 deg. F., the output under these conditions being 8,650 kW. In the second stage of development a new machine will be provided for this waste heat steam and the above-mentioned turbine will operate with steam at 400 p.s.i.g., 800 deg. F. The turbo-blower condensate passes through the feed heating train on the turbo-alternators, thus contributing considerably to overall economy by avoiding the need for steam extraction on the blower turbines.

The two 90,000 c.f.m. turbine-driven radial flow uncooled blowers (fig. 4) also operate from the high pressure steam supply of 400 p.s.i.g., 800 deg. F. They have five 60 in. dia. centrifugal impellers and deliver air at a maximum pressure of 32 p.s.i.g., being designed for high top pressure working on the furnace. The b.h.p. is 11,215 at 2,700 r.p.m. and control is by hydraulic governor giving an exceptionally wide speed range. Constant volume and anti-surge regulation is provided by Askania controls. Either of these units has ample capacity to meet the requirements of the single blast furnace now installed so that the other machine is always available as a standby.

PROCESS STEAM PLANT.

Two 720 b.h.p. back-pressure turbines meet the process steam requirements of the melting shop, coke ovens and blast furnace in addition to supplying heating steam to the administration block. Each of these is coupled through reduction gears to two cooling-water pumps in tandem (fig. 5), one of which supplies cooling water for any three of the main turbines while the second supplies water for blast furnace jacket cooling. The steam inlet conditions are the same as for the main turbines, i.e. 400 p.s.i.g. at 800 deg. F., and the exhaust steam is at 160 p.s.i.g., 660 deg. F.

WATER TREATMENT.

In order to increase the period between condenser overhauls, complete chlorination plant is provided to destroy and dislodge the nucleus of any slime fouling before it can develop to a degree sufficient to entrain suspended matter from the circulating water and affect heat transfer across the condenser tubes. The plant is automatic in operation, providing for separate and sequential treatment at each condenser inlet. The duration of the intermittent treatment is controlled by a programme clock, where the injection for any condenser not in use can be interrupted.

Town water is normally used for boiler feed purposes and the town reservoir water is treated by coagulation with sulphate of alumina rapid sand filtration and chlorination before being supplied to the site. However, the piping system is so arranged that Clyde water may be used in the boilers in an emergency, and sand filters are provided for this purpose. In accordance with modern boiler feed water treatment practice, and to ensure efficiency in operation, base exchange

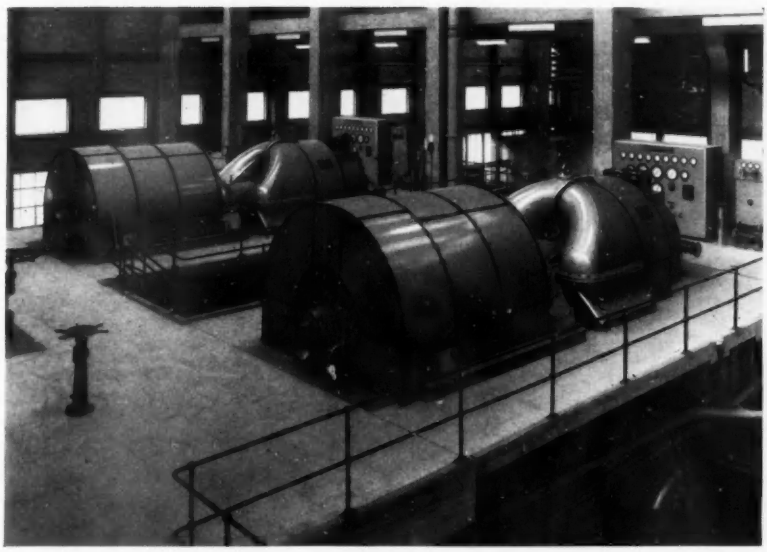

Fig. 4.—The 90,000 c.f.m. turbo-blowers.

plants are provided to reduce the hardness, in addition to low pressure dosing and high pressure boiler injection equipment to limit the pH value.

SWITCHGEAR.

The station is connected through ten-panel 33 kV, 750 MVA single-busbar metalclad switchgear to the South of Scotland Electricity Board 33 kV grid so that import and export of power is possible. This gear also controls the 33 kV supply to the adjacent works in the Colvilles group—Dalzell and Clyde Alloy. It is connected to the eleven-panel, 11 kV, 350 MVA single busbar metalclad oil- and compound-filled generator switchboard through two 20 MVA transformers with on-load tap-changing equipment (fig. 6).

Distribution within Ravenscraig Works is by an eighteen-panel, 11 kV, 250 MVA single busbar metalclad oil- and compound-filled switchboard connected to the 350 MVA board through two 10 MVA reactors with 6 per cent nominal reactance.

Two 1,500 kVA auxiliary transformers link the 250 MVA board with the 440 volt, 25 MVA auxiliary motor control board, which feeds eight centralised starter boards controlling 70 motors totalling 2,775 h.p. An 11 kV emergency supply feeder taken from Dalzell Works through a third auxiliary transformer serves as standby to the essential auxiliaries in the power station. The switchrooms are protected by automatic CO_2 fire-fighting equipment.

The control room (fig. 7), with a wide panoramic view of the whole of the inside of the station, measures 100 ft. $\times$20 ft. and accommodates control boards, relay boards and busbar protection boards for the 33 kV and 11 kV switchgear, in addition to supervisory equipment ; electrical, gas, and steam metering boards ; synchronising panels ; and 440 volt auxiliary control boards.

CONSTRUCTION AND ERECTION.

During the last quarter of 1954, Colvilles Ltd. arranged for the site to be cleared and levelled after earlier soil survey and ground proving. The average depth of earth removed from the power station site was nearly 30 ft. and during this early period the building design was

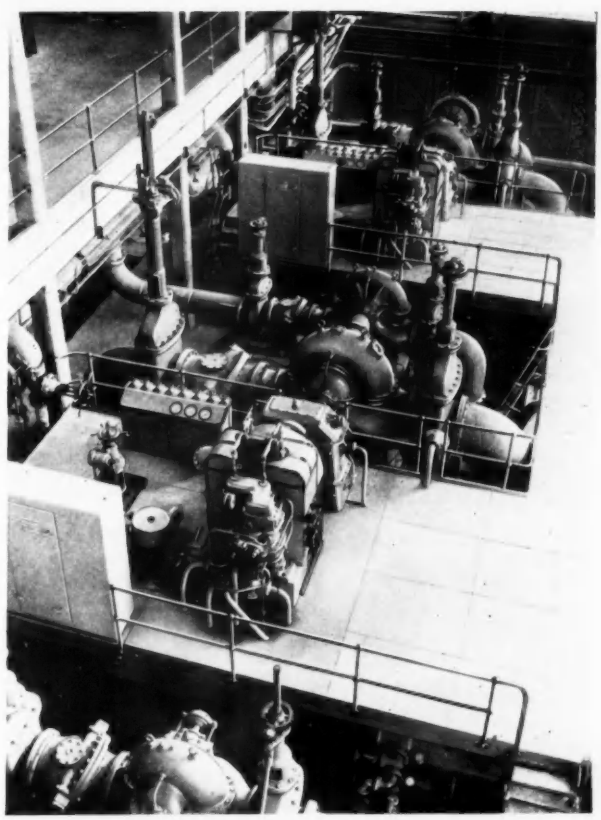

Fig. 5.—Back-pressure turbines driving cooling water pumps.

cleared with the civil engineers. Access to site was obtained by the G.E.C. during early December, and concrete pouring started on December 28, 1954. The first turbo-alternator, working from No. 1 boiler, was synchronised with the South of Scotland Electricity Board supply on December 18, 1956—within two years from the commencement of work—and the complete project was taken over on March 31, 1957.

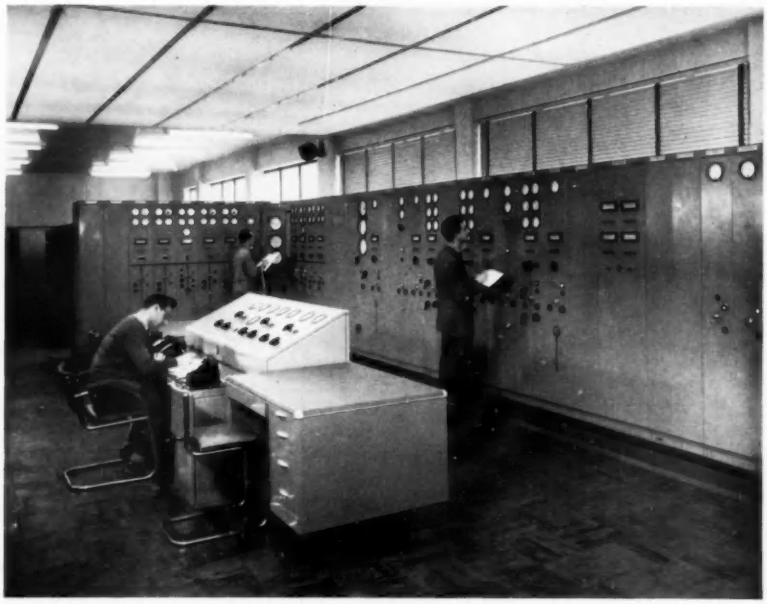

Fig. 7.—Control room.

MATERIALS HANDLING PLANT.

Associated with this project is the materials handling equipment, comprising ship unloading conveyors and storage bunkers, supplied by the G.E.C. at the General Terminus Quay, Glasgow, where the high grade ore for the blast furnace plant is brought by sea and unloaded. The two lines of conveyors from the unloaders are designed to pass 1,000 tons of ore per hour to the two lines of storage bunkers. From the bunkers the ore is loaded into hoppers which discharge into 35 ton wagons. There are four lines of hoppers, each line loading fourteen wagons from a single-point control, before the ore is transported to Ravenscraig.

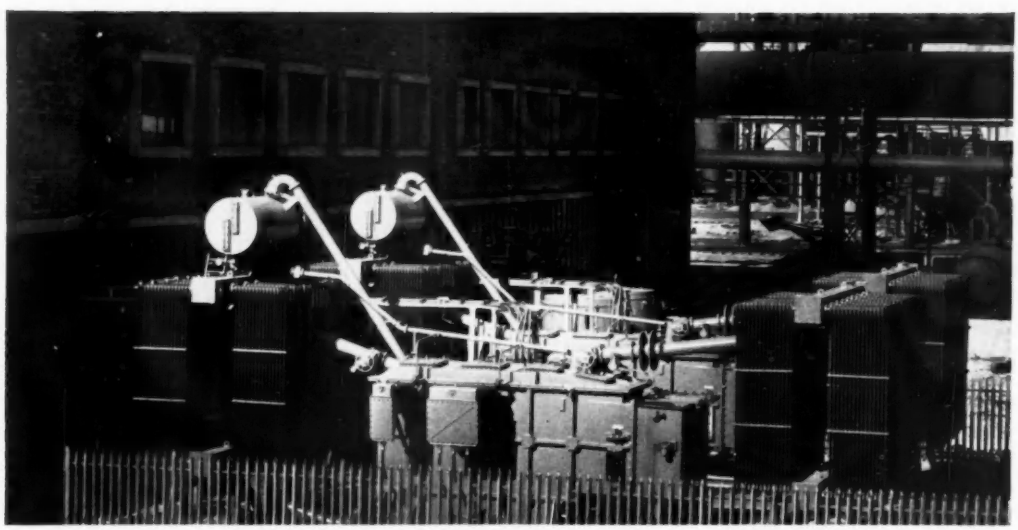

Fig. 6.—The two 20 MVA transformers with on-load tap-changing gear.

A Conversion Chart for use in the Calculation of Network Short Circuits

By A. W. BOWYER, A.M.I.E.E., and R. K. SETH, M.Sc., Grad.I.E.E.,
Protective Gear and System Planning Division, Witton.

AN appreciable proportion of the time involved in evaluating network short-circuits is taken up in converting known information from one basis to another before the actual network reduction calculations can be made, and in reconverting the information obtained from the network reduction into the required terms.

The labour of calculation and the likelihood of mistakes may be considerably reduced with the aid of the attached conversion chart.

USING THE CHART.

Two methods are commonly used for short circuit calculations. The first is the ohmic impedance method, for which a common voltage base is adopted and the ohmic impedance of all items of plant or feeders are referred to this base voltage. The second is the percentage impedance method for which a common MVA base is adopted and the plant and feeder percentage impedance are referred to the base MVA level. (It is not the purpose of this short article to describe these methods and the technique of network reduction, which are fully described elsewhere [1, 2, 3].)

The chart may be used with either method of calculation, and the necessary conversion operations made as listed below :—

A. OHMIC IMPEDANCE METHOD (COMMON kV BASE)

Operation	Known values	Value read off chart
1.	MVA rating of an item of plant and its percentage impedance.	Plant impedance in ohms referred to any system voltage.
2.	Source MVA rating.	Source impedance in ohms referred to any system voltage.
3.	An impedance in ohms related to a given system voltage.	Its equivalent impedance when related to any other system voltage.
4.	A total fault path impedance related to a given system voltage.	Fault level in MVA.

B. PERCENTAGE IMPEDANCE METHOD (COMMON MVA BASE)

Operation	Known values	Value read off chart
5.	Impedance of a feeder operating at a given voltage.	Equivalent percentage impedance referred to a base MVA.
6.	Source MVA rating.	Equivalent percentage impedance referred to a base MVA.
7.	MVA rating of an item of plant and its percentage impedance.	Equivalent percentage impedance referred to a base MVA.
8.	Fault path equivalent percentage impedance referred to a base MVA.	Fault level in MVA.

C. COMMON TO BOTH METHODS

Operation	Known values	Value read off chart
9.	Fault level in MVA and system voltage in kV.	Fault current in kiloamp.

Examples of these conversions are given below and their derivation indicated by the arrows and figures on the chart.

1. A 5 MVA transformer with a 12·3 per cent reactance has a reactance of 1·07 ohms referred to a base voltage of 6·6 kV.
2. A switchgear MVA rating of 150 MVA corresponds to a source impedance of 0·81 ohms at 11 kV.
3. An impedance of 0·19 ohms at 11 kV becomes 0·017 ohms at 3·3 kV.
4. A total fault path impedance of 14 ohms with a 22 kV base indicates a fault level of 35 MVA.
5. A 33 kV cable impedance of 0·3 ohms has a percentage impedance of 2·8 per cent when referred to a 100 MVA base.
6. A switchgear rating of 350 MVA corresponds to a 17 per cent impedance when referred to a 60 MVA base.

7. A 10 MVA reactor with a 4·2 per cent reactance has a 25 per cent reactance when referred to a 60 MVA base.
8. Using a 1 MVA base, a network reduces to a 7·4 per cent equivalent impedance indicating a fault level of 13·5 MVA.
9. With a 3·3 kV fault level of 9 MVA the fault current is approximately 1·6 kiloamp.

CONSTRUCTION OF THE CHART.

The attached chart, drawn on 6 cycle × 4 cycle logarithmic graph paper, does not cover all the values likely to be used in all fault calculations but merely those which are used in a majority of the applications. The following notes may assist anyone wishing to produce his own chart with different impedance and MVA ranges, or voltage bases.

If we plot the function $A=\frac{C_1}{B}$ (where C_1 is a constant) on log-log paper, with A co-ordinate horizontal with values increasing from left to right, and the B co-ordinate vertical with values increasing from top to bottom, we obtain a straight line with a slope of plus 45° to the horizontal. Similarly, if on the same graph we plot the function $A=C_2B$ (where C_2 is a constant) we obtain a straight line with a slope of minus 45° to the horizontal. Refer now to the conversion chart and to fig. 1. They consist of two graphs, side by side. On the left we have a vertical scale of MVA corresponding to B and a horizontal scale of impedance (ohms) corresponding to A. The relationship $A=\frac{C_1}{B}$ becomes Z (ohms) $=\frac{kV^2}{\text{MVA}}$.

For a given voltage we can calculate a single point and then produce a line at 45°, e.g. for the 11kV line, the impedance Z at 100 MVA$=\frac{11^2}{100}=1{\cdot}21$ ohms. In this way we can produce a series of parallel lines for the various voltage bases required.

The function $A=C_2B$ becomes $Z=\frac{1}{3\times kA^2}\times$ MVA and from this we can obtain the current grid lines, shown dotted on the conversion chart, e.g. for the 15 kA line, the impedance at 200 MVA$=\frac{200}{3\times 15^2}=$ 0·296 ohms.

On the right of the chart we have the same vertical scale of MVA as on the left. The horizontal scale is impedance expressed as a percentage and the function $A=\frac{C_1}{B}$ becomes Z (per cent)$=\frac{100\times\text{MVA base}}{\text{MVA}}$.

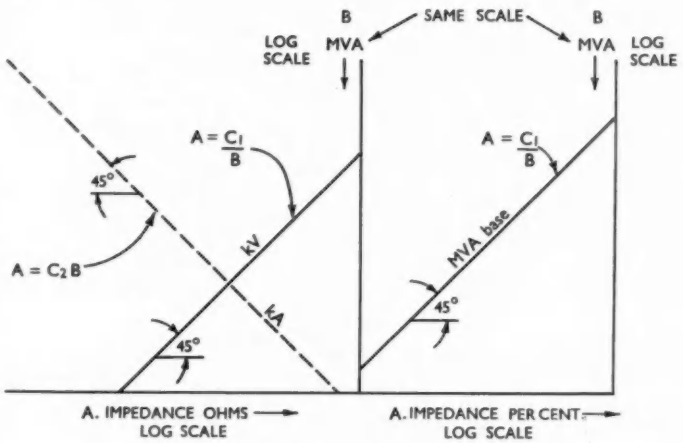

Fig. 1.—Derivation of voltage base and grid lines.

The grid is one of base MVA's and the lines are obtained by drawing a 45° line through the intersection of $Z=100$ per cent and the MVA level for the base MVA required.

REFERENCES.

1. Notes on the Calculation of Network Short Circuits, by C. J. O. GARRARD. *G.E.C. Journal*, Vol. VIII, pp. 62-77, February, 1937. (Reprints available on request.)
2. Fault Calculations, by C. H. W. LACKEY. Oliver & Boyd Ltd.
3. The J. & P. Switchgear Book, by R. T. Lythall.

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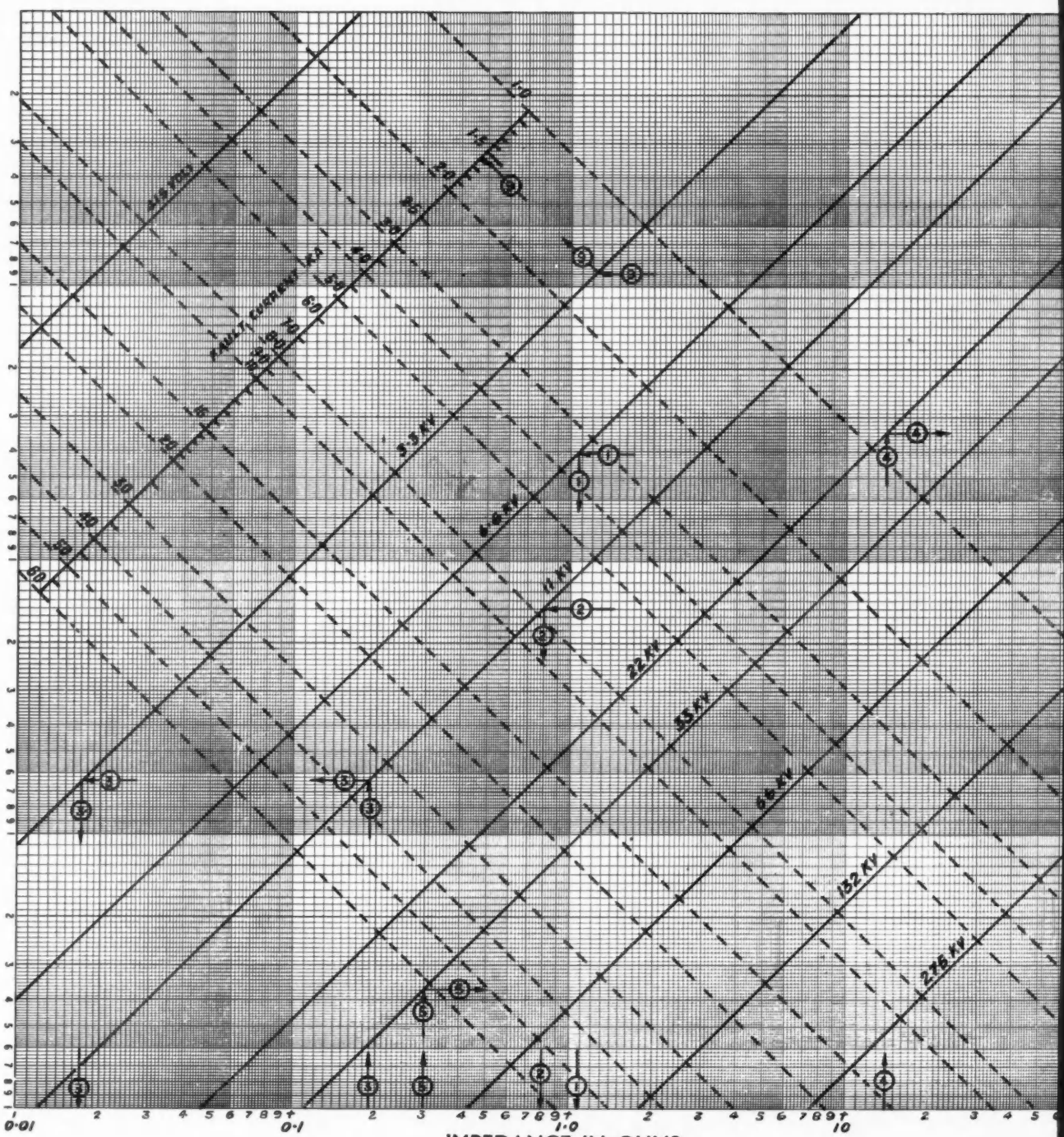
CONVERSION CHART FOR FAULT CA



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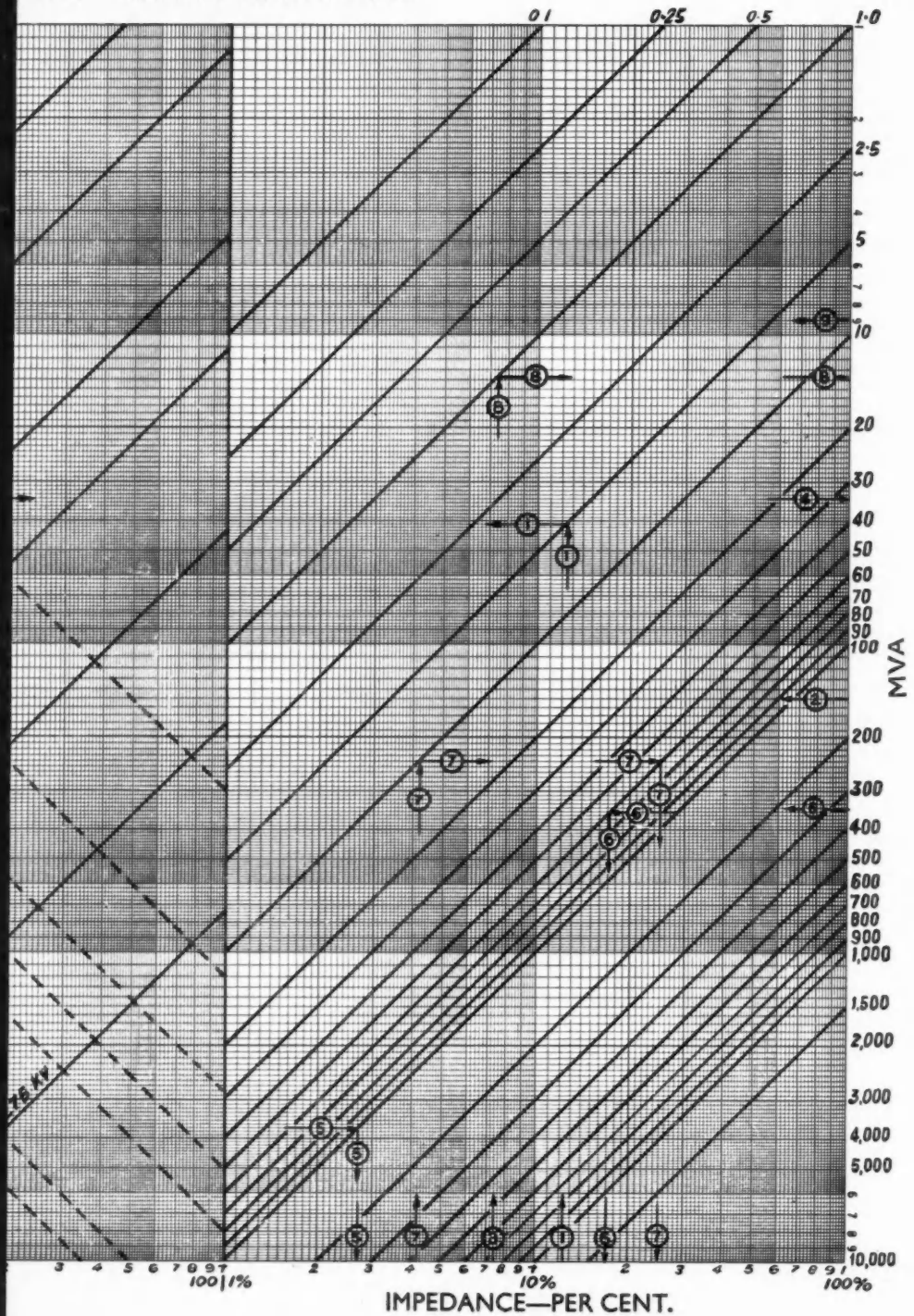

TECHNICAL LITERATURE

A digest of recent articles and papers by members of the G.E.C. and its associated companies

PLUG-IN T.R. TUBES FOR USE IN S BAND DUPLEXERS (692).*

By T. L. Dutt (Research Laboratories).

"*Le Vide*", *No.* 67, *pp.* 93-108, *January-February*, 1957.

In a pulsed radar equipment where common aerial working is adopted, it is of first importance to achieve low loss reliable switching of the aerial alternately to the transmitter and to the receiver. Poor switch performance can lead to a receiver noise factor worsening by several decibels from the optimum, due to crystal deterioration or excessive T.R. cell loss.

Over the past ten years or so, low loss, broadband T.R. cells of a non-tunable type have supplanted high-Q tunable switches in many radar equipments, yielding an improved performance particularly as regards the ability to withstand high power operation and in avoiding signal loss associated with the faulty tuning of the high-Q cell. The paper deals with the problems encountered in the development and manufacture of good cells, especially when operating powers were much increased.

THE USE OF FERROELECTRIC CERAMICS FOR VIBRATION ANALYSIS (695).*

By R. C. Kell, G. A. Luck and L. A. Thomas (Research Laboratories).

Journal of Scientific Instruments, *Vol.* 34, *pp.* 271-274, *July*, 1957.

The main advantage of ferroelectric ceramics of the barium titanate type for piezoelectric applications lies in their high dielectric constant, compared with the well-known single-crystalline piezoelectric materials such as quartz. Ferroelectric ceramics are used in accelerometers developed for the measurement of acceleration in vibration testing and in vibration strain gauges developed for the determination of the resonant frequencies of mechanical structures. The applications, construction and properties of these two devices are described.

THE PHYSICAL AND CHEMICAL PROPERTIES OF SOME NICKEL-ZINC FERRITE COMPOUNDS (698).*

By N. C. Tombs and J. Watkins (Research Laboratories).

Proceedings of the Institution of Electrical Engineers, *Vol.* 104, *Part B*, *pp.* 145-151, *Supplement No.* 5, 1957.

The work reported forms part of a general investigation aimed at elucidating the mechanisms giving rise to magnetic and dielectric losses in ferrites. For this purpose the nickel-zinc ferrite system was chosen as a simple system containing materials whose properties fall within a convenient range for measurement.

In particular, the paper describes the preparation and some properties of a series of nickel-zinc ferrites in which the iron content has been made less than the stoicheiometric value. The primary aim in preparing these materials was to find to what extent the resistivity at microwave frequencies could be increased in such iron-deficient preparations. Although an increase of the resistivity at 9.6 Gc/s from about 50 ohm-cm. to 500 ohm-cm. is obtained, this alone would not be adequate for practical materials. Other properties of the materials have been measured and their variation with iron content explained.

COMPUTATION OF CRYSTAL ADMITTANCE (699).*

By W. J. Lucas and P. B. Barber (Research Laboratories).

"*Electronic and Radio Engineer*", *Vol.* 34, *pp.* 454-458, *December*, 1957.

The paper summarises the results of a digital-computer programme designed to calculate the admittance, relative to 1/68 mho, of a coaxial crystal with the same dimensions as the CV2226 for various values of the video resistance R, spreading resistance r and barrier capacitance C over a frequency range 2,000-18,000 Mc/s. The equivalent circuit used in the calculation is discussed. From all the available measurements made on CV2226 crystals the variation with frequency of the admittance of an "average crystal" was obtained. It is shown that the computed curve corresponding to $r = 30$ ohms, $C = 0{\cdot}15$ pF and $R = 3{,}000$ ohms reproduces the "average curve" extremely well. Further, it is shown that the spread in the measured admittance of a batch of crystals at a given frequency can be accounted for by varying r and C in the manner these two parameters are expected to vary in an actual crystal.

SOME PROPERTIES OF CIRCULAR WAVEGUIDES CONTAINING FERRITES (700).*

By P. J. B. Clarricoats (Research Laboratories).

Proceedings of the Institution of Electrical Engineers, *Vol.* 104, *Part B*, *pp.* 286-295, *Supplement No.* 6, 1957.

The paper describes some results of an experimental investigation of the propagation behaviour of circular waveguides containing longitudinally magnetised ferrite rods. Measurements have been made at 9·250 kMc/s using nickel-zinc ferrite. Reasonable correlation is obtained between experimental and theoretical results for the limiting cases of the thin ferrite rod and the waveguide completely filled with ferrite. Factors determining the propagation behaviour in the partially filled waveguide are discussed and illustrated by experimental results. The dependence of propagation behaviour on ferrite-rod diameter is studied in detail using polystyrene foam and polystyrene as supporting media.

CONFIDENCE LIMITS FOR THE RANGE OF A SEARCH RADAR (703).*

By C. Stevens (Applied Electronics Laboratories).

Applied Statistics, *Vol.* 6, *pp.* 214-222, *No.* 3, 1957.

The determination of confidence limits for the percentage points of a normal distribution is a problem with an exact, but somewhat troublesome, solution. This paper describes a fairly simple approximate solution, which was found to be sufficiently accurate.

SECONDARY ELECTRON EMISSION FROM BARIUM DISPENSER CATHODES (720).*

By I. Brodie and R. O. Jenkins (Research Laboratories).

British Journal of Applied Physics, *Vol.* 8, *pp.* 202-204, *May*, 1957.

Measurements of the total secondary electron emission coefficient under electron bombardment δ have been made at room temperature on "L" cathodes and porous tungsten cathodes impregnated with barium calcium aluminates.

For " L " cathodes δ decreases with increasing porosity due to the increased surface roughness but δ is always above that for clean tungsten, due to the activation of the surface by adsorbed layers. For the impregnated cathode, δ increases with increasing porosity due to the larger contribution from the impregnant in the pore ends which has a larger value of δ than the surrounding activated tungsten. δ for the impregnated cathode is above that for the " L " cathode and comparable with that for bulk barium oxide. Decay of δ under electron bombardment is observed in the case of the impregnated cathode but the initial value can always be recovered by heating.

THERMAL AND ELECTROLYTIC ACTIVATION OF PHOTOCONDUCTIVITY IN CdS CRYSTALS (723).*

By J. Woods (Research Laboratories).

Journal of Electronics and Control, Vol. 3, *pp.* 225-235, *August*, 1957.

The photoconductivity and dark conductivity of cadmium sulphide crystals grown by the Frerichs technique can be increased by heat treatment in vacuum or in air. Free cadmium is present on the surface and at internal cracks of a crystal as grown. Heating at 100-300 deg. C. in the presence of the free cadmium leads to a non-stoicheiometric excess of cadmium in the lattice, and considerable activation is achieved. At temperatures in excess of 300 deg. C. thermal dissociation occurs, sulphur is lost and a further non-stoicheiometric excess of cadmium is formed. The application of an electric field assists dissociation by electrolytic processes. The activation of cadmium sulphide crystals resulting from dielectric breakdown previously reported by the author (Woods 1956) can now be understood.

Heat treatment in vacuum produces a high surface conductivity accompanied by a high photosensitivity to blue light. Both are reduced by exposure to oxygen at room temperature. Heat treatment in air produces electron trapping levels which are not created by corresponding treatment in vacuum.

LATTICE CHANGES IN SPINEL-TYPE IRON CHROMITES (726).*

By M. H. Francombe (Research Laboratories).

Journal of Phys. Chem. Solids, Vol. 3, *Nos.* 1/2, *pp.* 37-43, 1957.

X-ray powder studies have been made of structure deformations arising on cooling spinel-type iron chromite compounds with compositions of the form $FeFe_{2-x}Cr_xO_4$ below room temperature. Approximate measurements of Curie temperatures have also been caried out over the entire composition range $x = 0$ to $x = 2$.

A tetragonal distortion with c/a greater than one is first detected at $x = 1{\cdot}0$ and increases in magnitude up to $x \geqslant 1{\cdot}3$. With higher values of x the deformation is orthorhombic and results from a separate [001] expansion and [100] contraction, giving the sequence cubic $\rightarrow$ tetragonal $\rightarrow$ orthorhombic on cooling. As x is increased to 2 the second of these deformations predominates and in $FeCr_2O_4$ the lattice distortion is tetragonal with c/a less than one.

The nature and magnitude of the distortions are considered in relation to the probable cation distribution in tetrahedral and octahedral sites. The observed structure changes in these compounds are difficult to explain on the theory of covalent bonding of either octahedral or tetrahedral cations. It is suggested that the deformations may arise from strong negative *B-B* type interactions of the form Fe^{3+}–Fe^{3+}, Fe^{3+}–Cr^{3+} or Cr^{3+}–Cr^{3+} operating through super-exchange or semicovalent-exchange mechanisms.

MIXING AND FLOW IN TANK FURNACES (727).*

By P. A. Michaels (Research Laboratories).

Journal of the Society of Glass Technology, pp. 118*T*-136*T*.

This paper contains a review and discussion of published work on mixing and flow in tank furnaces. A bibliography is included. It is shown that a tank furnace is not an efficient mixing device, and cannot produce uniform glass from badly mixed batch.

STRUCTURE CHANGES IN SOME NON-STOICHEIOMETRIC OXIDES OF THE TRANSITION ELEMENTS (729).*

By H. P. Rooksby (Research Laboratories).

Transactions of the British Ceramic Society, Vol. 56, *pp.* 581-589, *No.* 11, 1957.

The magnitude of the distortion of the cubic structure of FeO which occurs on cooling below the antiferromagnetic Neel temperature of −70 deg. C. is affected by the iron concentration, which can be varied over a relatively wide range. With decreasing iron concentration, and thus increasing departure from stoicheiometric FeO, the structure deformation diminishes. An analogous structure transition is observed in NiO below 250 deg. C., though even for a near-stoicheiometric composition the effect is smaller than with FeO. Evidence has been obtained, however, that the structure-cell distortion is similarly affected by the degree of departure from stoicheiometry. It appears likely that the defects in the metal atom lattice, which are a consequence of non-stoicheiometry, cushion the magnetostrictive forces which are the cause of the structure distortion. The transition temperature itself is not much modified by differences in composition. In investigations of the influence of various impurities in solid solution on the structure of NiO, FeO was found to give a unique result. In a concentration as low as 3 mol. per cent the magnitude of the structure deformation becomes vanishingly small even when measured at −180 deg. C. It is concluded that this is because non-stoicheiometry is enhanced by the incorporation of FeO, whereas with the other additives a near-stoicheiometric composition is maintained.

SEMICONDUCTOR LIFETIME AS A FUNCTION OF RECOMBINATION STATE DENSITY (728).*

By D. H. Clarke (Research Laboratories).

Journal of Electronics and Control, Vol. 3, *pp.* 375-386, *October*, 1957.

The analysis of the Shockley-Read model is extended to describe the transient behaviour. The results are compared with those already given by Fan and by Rittner, and it is concluded that the latter cease to be valid at high recombination state densities. The relation between steady state and transient measurements of photoconductivity is examined, and some numerical examples are presented.

GEOMETRICAL EFFECTS IN TRANSVERSE MAGNETORESISTANCE MEASUREMENTS (730).*

By J. R. Drabble and R. Wolfe (Research Laboratories).

Journal of Electronics and Control, Vol. 3, *pp.* 259-266, *September*, 1957.

The effect of finite length-to-width ratio and of probe positions on measurements of resistivity in a transverse magnetic field is investigated for various Hall angles. It has been shown by Wick that the Hall effect causes an increase in the resistance between the end contacts of a rectangular specimen. In this paper, Wick's method is extended to include the case of measurements made between probes symmetrically placed at various distances from the ends. It is shown that the " Hall resistance " is negligible when the probes are placed at a distance from the ends greater than the width of the specimen. Graphs are included which give the fractional change of resistance for various probe positions and Hall angles for specimens of any length-to-width ratio greater than two.

TEMPERATURE CHARACTERISTICS OF BARIUM STRONTIUM LITHIUM SILICATE PHOSPHORS (731).*

By A. H. McKeag (Research Laboratories).

Journal of the Electrochemical Society, Vol. 105, *pp.* 78-81, *February*, 1958.

The changes in spectral emission, efficiency, and temperature stability are discussed which result from changes in the following variable parameters in phosphor preparation: the barium : strontium ratio, lithium content, base : acid ratio, activator concentrations, and firing conditions. For practical application in jacketed high pressure mercury vapour lamps, compositions within a critical base : acid ratio of 3RO : 1·8 to 1·9 SiO_2 have produced the best results.

A REVIEW OF THE MEASUREMENT OF THE QUANTUM EFFICIENCY OF INORGANIC PHOSPHORS (732).*

By J. Tregellas-Williams (Research Laboratories).

Journal of the Electrochemical Society, Vol. 105, *pp.* 173-178, *March*, 1958.

The importance of the knowledge of the quantum efficiency of any phosphor is widely accepted ; apart from its theoretical importance in the consideration of the mechanism of the processes involved in luminescence, it is a valuable guide to the luminous efficiency which may be expected from a phosphor when incorporated in a lamp. Discrepancies between the precise values given by various authors for particular phosphors are still rather wide, as are the differences in the methods of measurement. This paper is intended to review both the published data and the methods used, in the light of original work on various phosphors by some of these methods.

The reported values of quantum efficiencies for various phosphors are tabulated, and it is noted that existing figures for sulfide phosphors appear to be variable but that, in general, efficiencies of about 50 per cent appear to be the rule. The only group where agreement is reasonable is the halophosphates : other phosphors require further study to resolve anomalies.

THE EFFECT OF GRINDING ON THE STRUCTURE AND LUMINESCENCE OF ZINC AND ZINC-CADMIUM SULPHIDES (734).

By M. A. Short and E. G. Steward (Research Laboratories).

Zeitschrift für Physikalische Chemie Neue Folge, Vol. 13, *Nos.* 5-6, *pp.* 299-315, 1957.

An investigation has been made of the effects of grinding on the crystal structure and photoluminescence of cubic and hexagonal *ZnS-Ag* and some members of the hexagonal *(Zn, Cd)S-Ag* solid solution series.

On grinding *ZnS-Ag*, the photoluminescence brightness of the hexagonal form was found to drop more rapidly than that of the cubic form. This and the changes in colour that occurred are discussed in terms of the inversion towards a cubic structure which occurs when the hexagonal sulphides are ground. The decrease in brightness of the zinc-cadmium sulphides showed an anomalous behaviour with respect to composition, but an approximately exponential relation between brightness and proportion of residual hexagonal stacking was found to hold for each composition. For a given amount of grinding, the extent of the structural change increased with zinc content and this has been interpreted in terms of the energy differences between the hexagonal and cubic forms of *ZnS* and *CdS*.

p-n-p-n SWITCHING DIODES (737).*

By A. K. Jonscher (Research Laboratories).

Journal of Electronics and Control, Vol. 3, *pp.* 573-586, *December*, 1957.

The paper describes silicon diodes of *p-n-p-n* structure which exhibit rapid switching from a high-resistance to a low-resistance state, similar to that described recently by Moll *et al.* Two types of characteristics are shown, those switching on both the " forward " and " reverse " branches and those giving ordinary diode forward behaviour and switching on the " reverse " branch only. A theoretical treatment is given accounting for this behaviour and discussing the nature of the conduction mechanism in the low-resistance state for both directions of current flow.

OPEN SPACE LIGHTING.

By M. W. Peirce (Illuminating Engineering Dept., Head Office) and H. F. Stephenson (Research Laboratories).

Transactions of the Illuminating Engineering Society, Vol. 22, *pp.* 209-231, *No.* 8, 1957.

Most open space lighting applications have features in common and the paper collates the methods and equipment used and cites typical installations. The extent to which conventional lighting equipment can provide the light distributions needed is examined and the relative merits of low and high mounted schemes discussed. Methods of restricting glare are described. Some of the techniques employed in computing installations and in training floodlights, especially with high-mounted schemes, are included.

ELECTROLUMINESCENCE AND ITS APPLICATIONS.

By J. N. Bowtell (Research Laboratories).

Journal of the Institution of Electrical Engineers, Vol. 3 *(New Series), pp.* 454-459, *August*, 1957.

Phosphorescence has puzzled man from early times. With increasing rationalism came the conception of " cold light ", but not until the elucidation of atomic structure was any explanation forthcoming. The author describes the stimulation of luminescence by alternating electric fields, and the applications and limitations of the phenomenon.

ELECTROLUMINESCENCE OF SEMICONDUCTING DIAMONDS.

By R. Wolfe and J. Woods (Research Laboratories).

The Physical Review, Vol. 105, *pp.* 921-922, *February* 1, 1957.

Electroluminescence has been observed in Type IIb diamonds. With both alternating and direct current, the light is emitted in the vicinity of a point contact electrode when this electrode is negative. The spectrum consists of a single broad band centred at 4400 A. The variation of the electroluminescent intensity with current voltage and frequency is reported. This behaviour is typical of carrier-injection electroluminescence.

CIRCUIT TECHNIQUES ASSOCIATED WITH TRANSISTOR BROADCAST RECEIVERS.

By J. N. Barry (Research Laboratories).

Electronic Engineering, Vol. 29, *pp.* 408-415, *September, and pp.* 478-483, *October*, 1957.

This article outlines some of the special circuit problems which arise due to the use of transistors in sound broadcast receivers, and discusses technical solutions which can be adopted to overcome them. The particular cases of battery portable and car receivers are both considered in some detail. An assessment of the effect of these technical solutions on receiver performance and economics is also made, and detailed performance figures for six different receiver designs are presented. The latter include four transistor portables, a valve portable and a transistor car radio. In the concluding section, any differences which the introduction of more recent types of transistor might make are discussed briefly, with particular reference to the case of v.h.f., f.m. receivers.

GALVANOMAGNETIC EFFECTS IN N-TYPE BISMUTH TELLURIDE (755).*

By J. R. Drabble, R. D. Groves and R. Wolfe (Research Laboratories).

Proceedings of the Physical Society, Vol. 71, *Part* 3, *pp.* 430-443, 1958.

The resistivity, Hall coefficients and low field magneto-resistance coefficients associated with current flow in the cleavage planes have been measured at 77 deg. K. on a number of n-type specimens of bismuth telluride. The resistivity and Hall coefficient measurements were extended up to room temperature. The experimental results are given and are shown to be reasonably consistent with a many-valley model of the band structure in which the energy minima are situated on the reflection planes. The parameters associated with this model are evaluated and used to relate the two Hall coefficients to the density of carriers. These relations are used to obtain the conductivity mobility of electrons for current flow in the cleavage planes. This mobility varies as $T^{-1\cdot68}$ over the temperature range 150 deg. K. to 300 deg. K. and has a value of 1,250 $cm.^2sec.^{-1}v^{-1}$ at room temperature.

THE DESIGN OF FUNCTION GENERATORS USING SILICON CARBIDE NON-LINEAR RESISTORS.

By E. Brown and P. M. Walker (Applied Electronics Laboratories).

Electronic Engineering, Vol. 30, *pp.* 154-158, *March*, 1958.

Silicon carbide resistors, the effective current-voltage characteristics of which have been modified by series and parallel linear resistors, are employed as input or feedback components of an operational amplifier to obtain non-linear function generators. The design of square law and sine units having a high accuracy is described in detail.

A SIMPLE TENSILE TESTING MACHINE FOR VERY FINE WIRES.

By A. E. Widdowson (Research Laboratories).

Journal of Scientific Instruments, Vol. 35, *pp.* 100-101, *March*, 1958.

In recent years the development of radio receiving valves of improved performance has necessitated the manufacture of control grids made with extremely fine tungsten wire, wound to a very close pitch. It is therefore necessary to be able to measure the mechanical properties of this wire, which is usually between 5 and 10 μ in diameter. This involves the measurement of a breaking load which may be as small as 5g, and a maximum elongation of about 2 per cent. When an effort was made to test these wires in standard tensile test machines, very misleading results were obtained, due partly to the inertia of the moving parts and partly to the difficulty of adequately holding the very fine wire in the jaws of the machine. The special instrument described in this article was therefore devised to overcome these difficulties and facilitate the handling of this extremely fine wire. By this means stress/strain curves can be obtained for fine tungsten wires as small as 5μ in diameter.

ELECTRONIC DEVICES EMPLOYING CATHODE-RAY BEAMS.

By L. S. Allard (Research Laboratories).

British Communications and Electronics, Vol. 4, *pp.* 620-625, *October*, 1957.

Cathode-ray beams are being applied to an increasing number of diverse applications and undoubtedly these will be extended in the future. This article outlines the main types of tubes utilising cathode-ray beams and indicates their particular applications. The categories of tubes considered are classified under the four main headings of tubes producing a light output, tubes utilising charge storage, tubes utilising controlled cathode-ray beams, and tubes utilising secondary emission. In the section on charge storage, an application of the principle to a digital computer is described.

A SURVEY OF THE THEORY AND APPLICATIONS OF FERRITES AT MICROWAVE FREQUENCIES.

By P. J. B. Clarricoats and A. G. Hayes (Applied Electronics Laboratories), and A. F. Harvey.

Proceedings of the Institution of Electrical Engineers, Vol. 104, *Part B, pp.* 267-282, *Supplement No.* 6, 1957.

The paper opens with a brief review of gyromagnetic media in general, followed by a more detailed description of the microwave behaviour of a ferromagnetic medium, of which ferrites form a suitable class of material. The general physical properties of ferrites are outlined briefly, together with a description of several of the mechanisms to account for the dispersion which occurs in their r.f. permeability. The propagation of an electromagnetic wave through an infinite ferrite medium is considered. The properties of different guided systems containing ferrites are then studied. The behaviour of various ferrite waveguide structures is described and their applications are suggested. Most of the data quoted are from published papers, but in a few instances some unpublished work of the authors has been included for completeness. An extensive bibliography completes the survey.

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